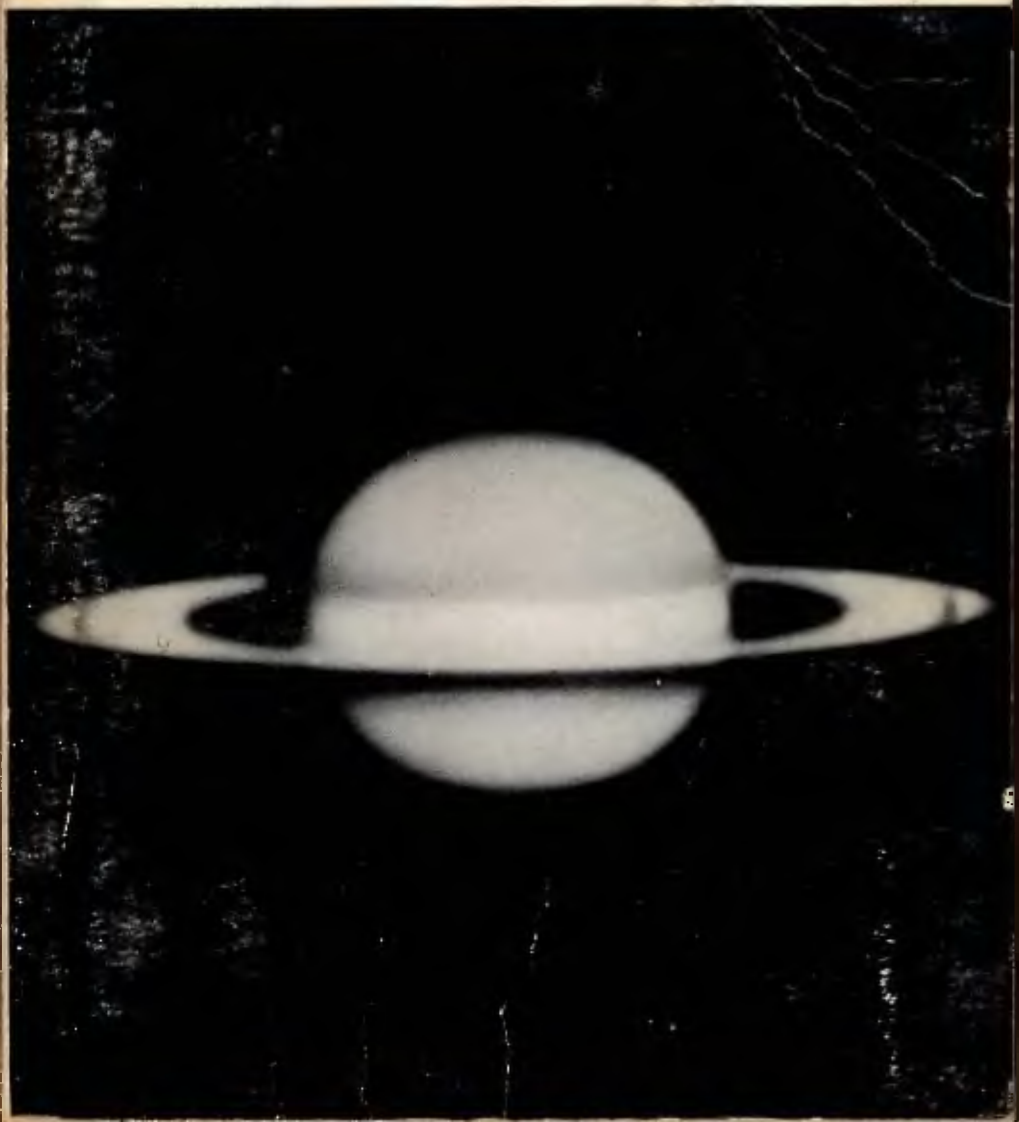
1964 Yearbook of Astronomy

Editor J. G. PORTER Associate Editor PATRICK MOORE



YEARBOOK OF ASTRONOMY 1964

EDITED BY
J. G. PORTER

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Contents

Preface · vii

Notes on the Star Charts · 1

The Star Charts · 4–29

The Planets in 1964 · 30

Phases of the Moon, 1964 · 31

The Planets and the Ecliptic · 32

Notes on the Planets in the monthly diagrams · 33

Monthly Notes, with diagrams of planetary orbits · 36–71

Eclipses, 1964 · 72

Occultations · 73

Comets in 1964 · 73

Meteors · 75

Minor Planets in 1964 · 76

Some Events of 1965 · 77

Articles

The Distance of the Sun · *J. G. Porter* · 78

With Mariner 2 to Venus · *H. G. Miles* · 83

Selenology – or Geology Applied to the Moon · *Peter J. Cattermole* · 92

The Great Red Spot on Jupiter · *W. E. Fox* · 100

Telescope Mountings · *Henry Wildey* · 107

Astronomy and Navigation · *Henry Brinton* · 115

The Surface of Saturn · *H. N. D. Wright* · 123

Planetary Nebulae · *Colin A. Ronan* · 132

Harrison, Maskelyne and the Longitude Problem · *P. S. Laurie* · 138

The Short-period Comets · *J. G. Porter* · 146

Recent Advances in Astronomy · *Patrick Moore* · 158

Some Recommended Books · 165

Astronomical Societies · 170

Glossary of Astronomical Terms · 175

Some Interesting Telescopic Objects · 198

Biographical Notes on Contributors · 214

Preface

This issue of the *Yearbook of Astronomy* follows the arrangement adopted last year. The year 1964 promises to be full of interest from the astronomical point of view – indeed, all the physical sciences may well be involved. The achievement of a U.S. team of space scientists in sending an interplanetary probe to the planet Venus is likely to be followed at the end of 1964 by the launching of another Mariner to the planet Mars, and this, if successful, should solve some of the problems that make this planet so interesting, as well as presenting us with others as yet unknown. At the other extreme, many scientific societies will be celebrating the fourth centenary of the birth of Galileo, who is justly regarded as one of the founders of modern science. In these four hundred years astronomy has undergone many changes, particularly in its methods, while the focus of interest has shifted from the solar system to the distant nebulae, from the mere cataloguing of positions to the application of the laws of physics to the formation and constitution of the stars. It is most interesting to notice how the modern space sciences have once again directed attention to the problems of the solar system. The articles which follow the monthly notes cover some of these topics, while there are also practical articles on telescope mountings and on the art of navigation. It is just two hundred years since Harrison solved the problem of navigation with his marine chronometer, and Mr Laurie's unique knowledge of the history of the Royal Observatory is well displayed in his article on Harrison's work. The latest results of the space scientists in their study of Venus are also described, and although these must not be regarded as final, they do at least show that there is still quite a lot to be learned about the solar system.

New readers will find that all the information in this *Yearbook*

is given in descriptive or diagrammatic form; the position of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis, 17*s.* 6*d.*) invaluable, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and American readers will also find details of forthcoming events given from time to time in the pages of the monthly *Sky and Telescope*; this magazine also publishes complete details of all occultations visible in North America.

Throughout this volume time is expressed in Greenwich Mean Time; that is, Summer Time is ignored, and the 24-hour clock is used, the day beginning at midnight. The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 4 to 27 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the brighter stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of 62½ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to 62½ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 30.

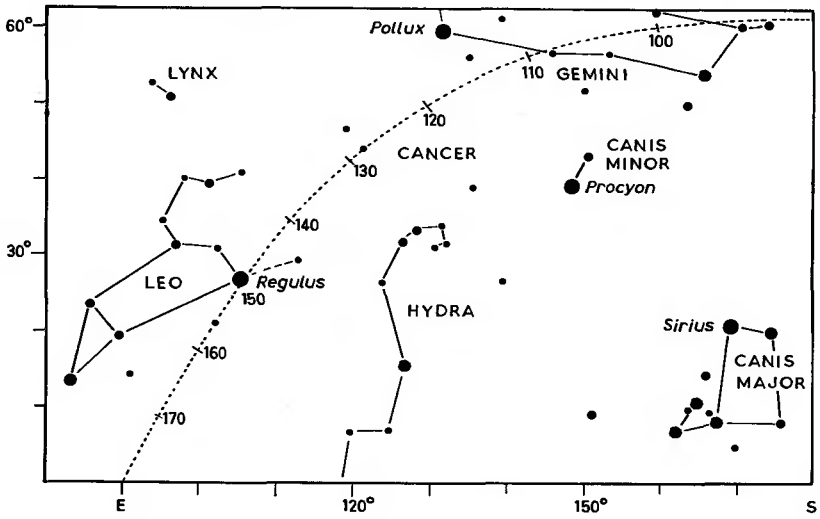
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 28 and 29, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

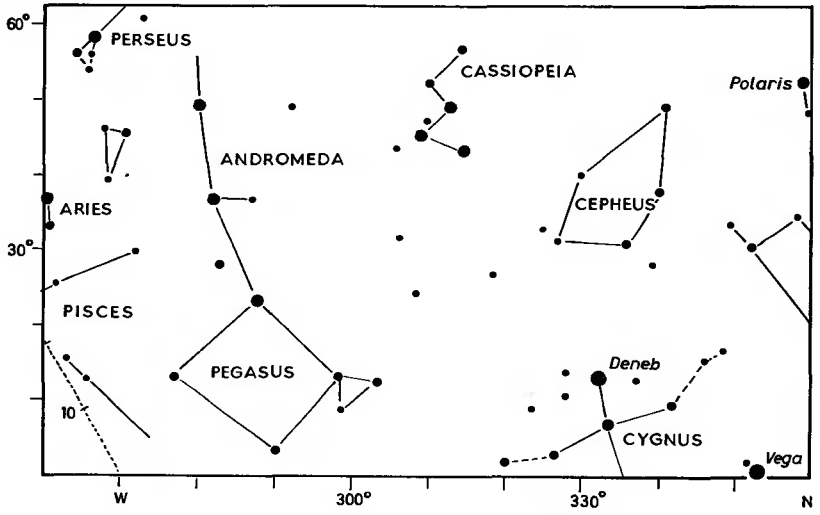
The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 28, the N-S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 14 and 15, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

1L

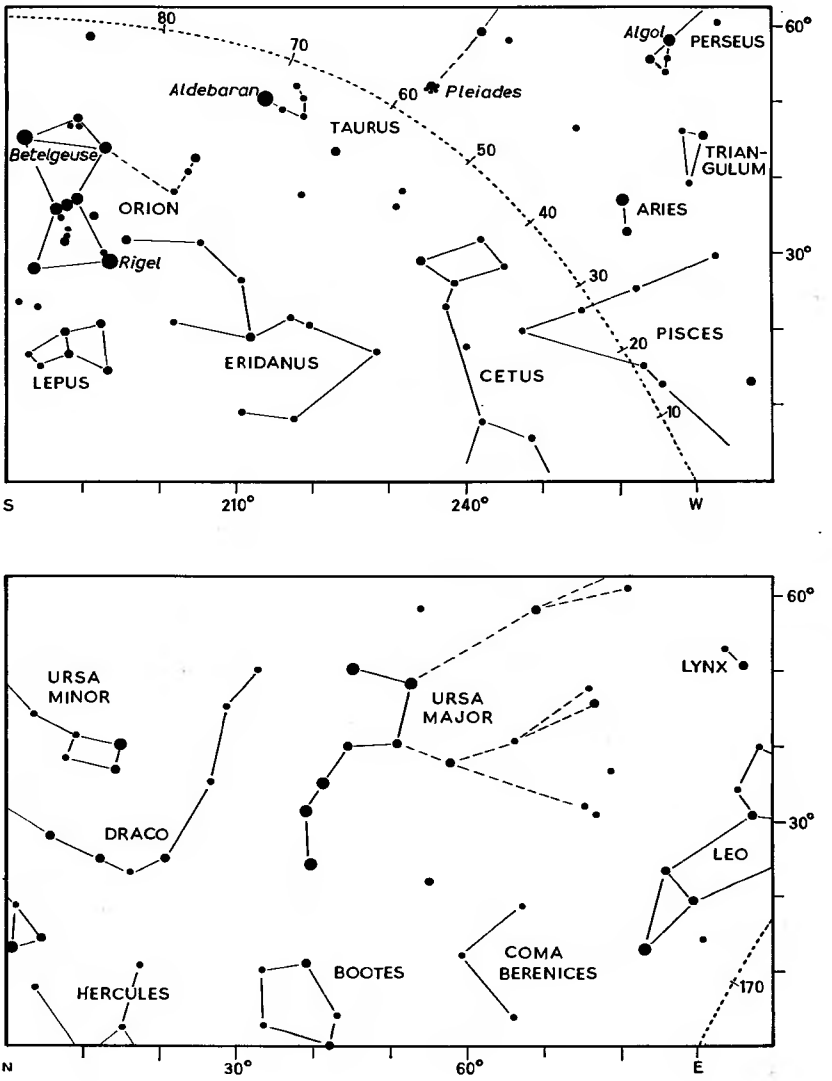
October 6 at	5h	October 21 at	4h
November 6 at	3h	November 21 at	2h
December 6 at	1h	December 21 at	midnight
January 6 at	23h	January 21 at	22h
February 6 at	21h	February 21 at	20h





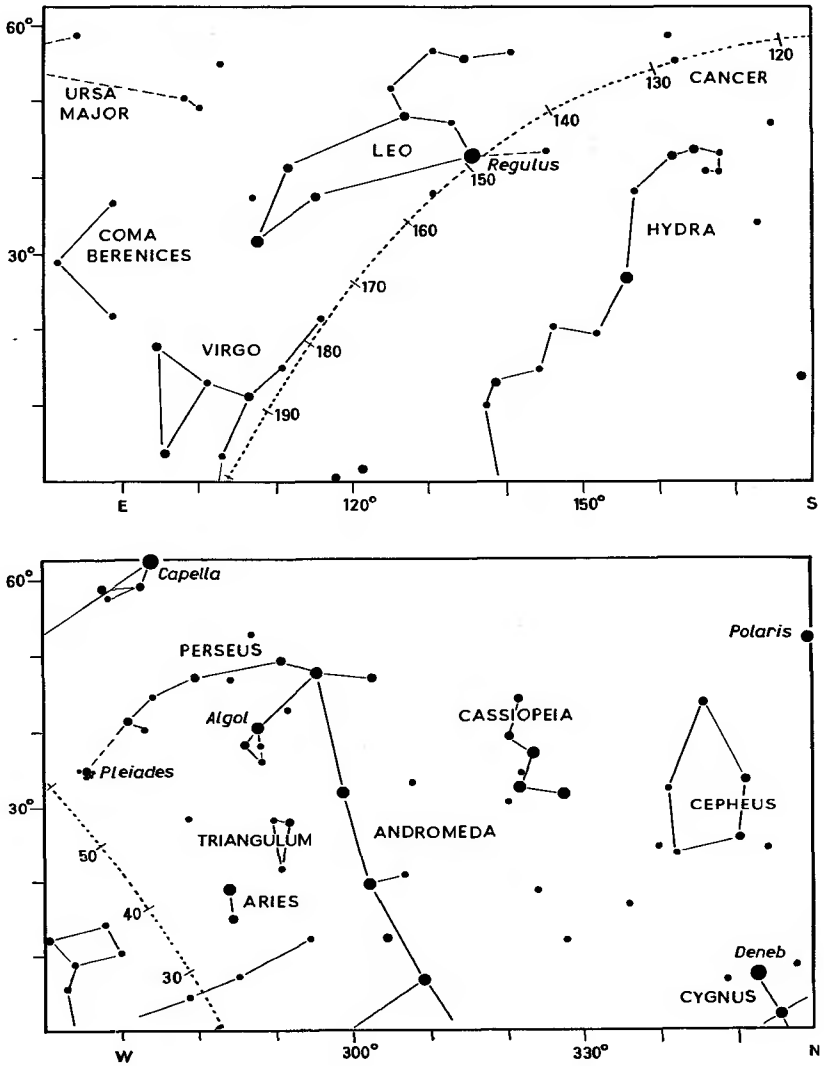
October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h

1R



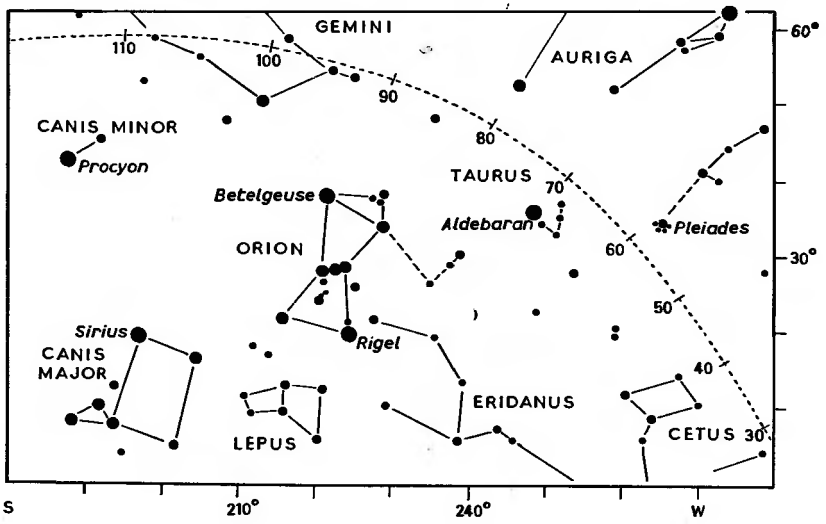
2L

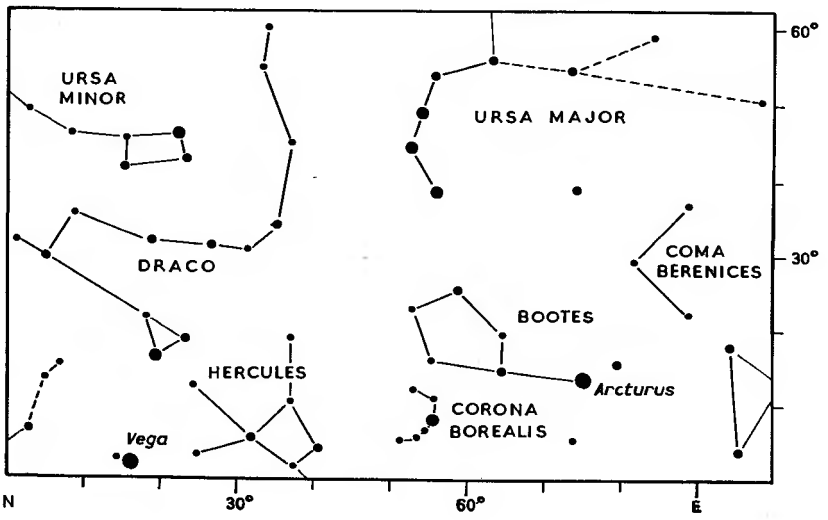
November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h



November 6 at	5^h	November 21 at	4^h
December 6 at	3^h	December 21 at	2^h
January 6 at	1^h	January 21 at	midnight
February 6 at	23^h	February 21 at	22^h
March 6 at	21^h	March 21 at	20^h

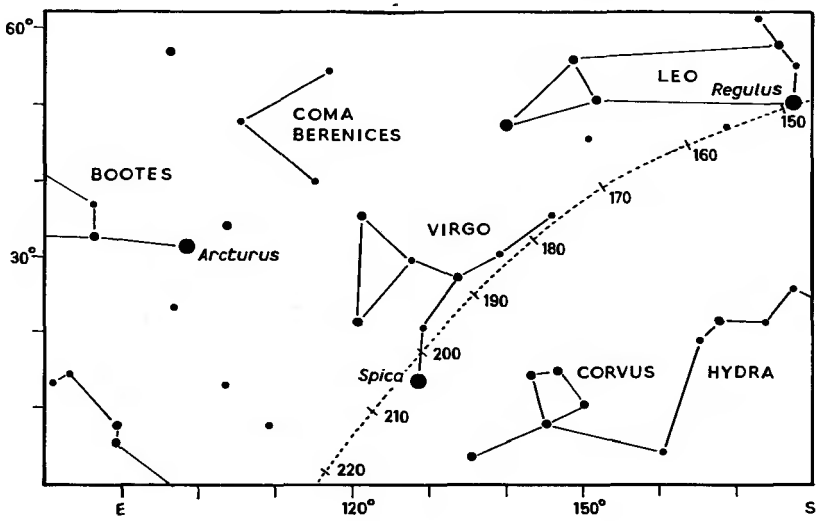
2R

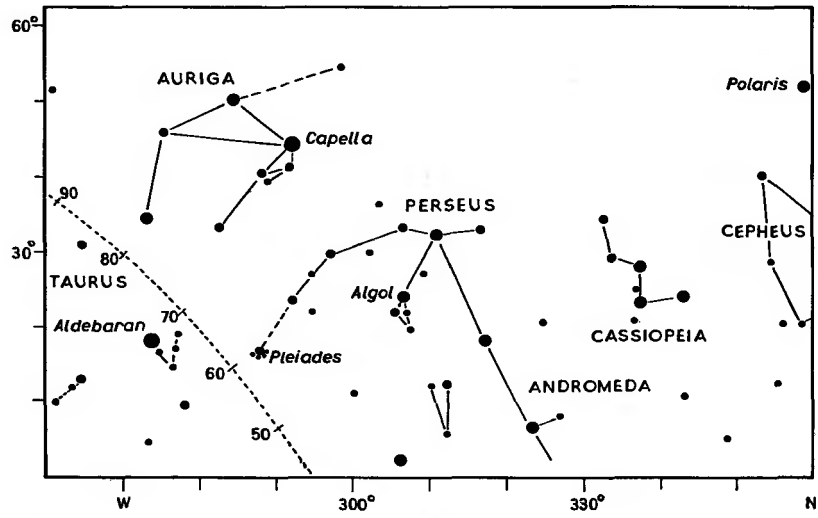




3L

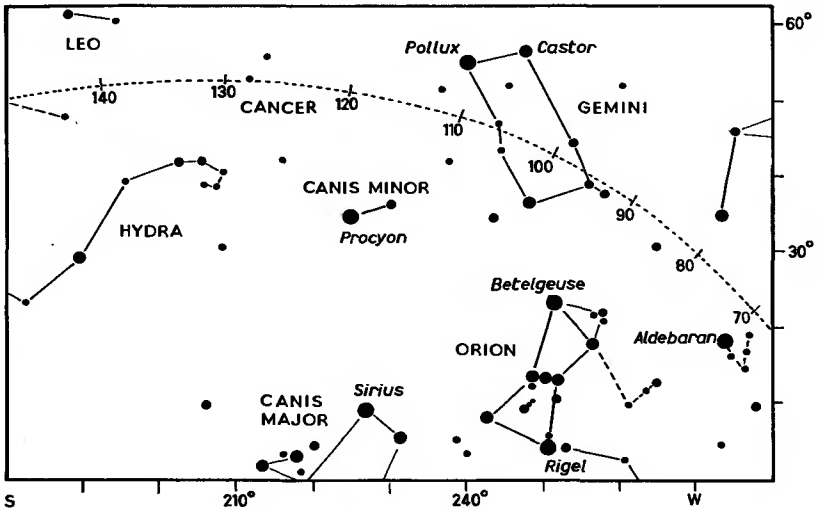
December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

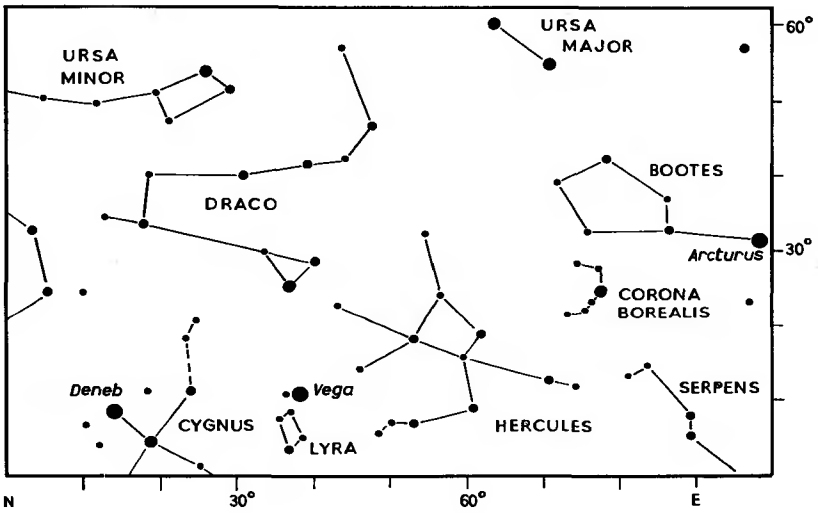




December 6 at	5h	December 21 at	4h
January 6 at	3h	January 21 at	2h
February 6 at	1h	February 21 at	midnight
March 6 at	23h	March 21 at	22h
April 6 at	21h	April 21 at	20h

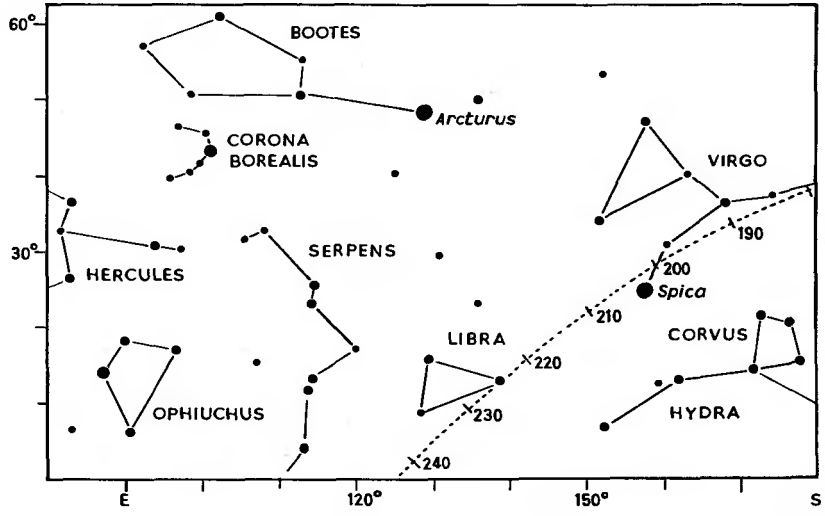
3R

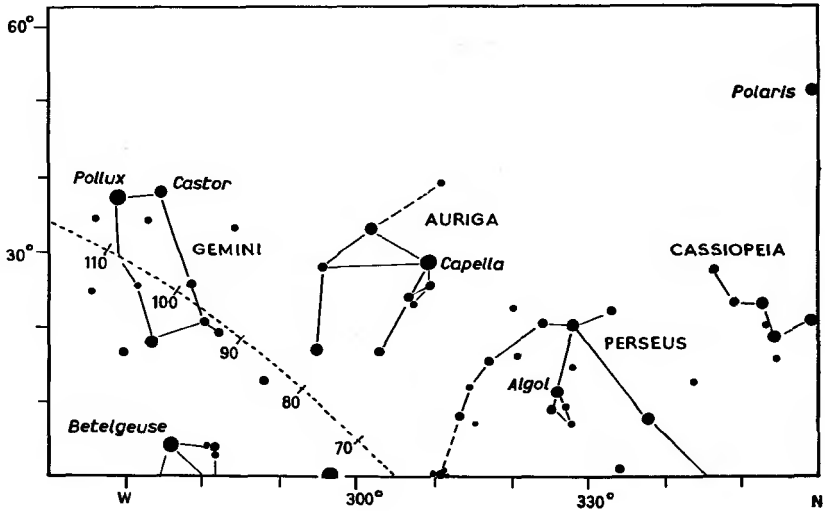




4L

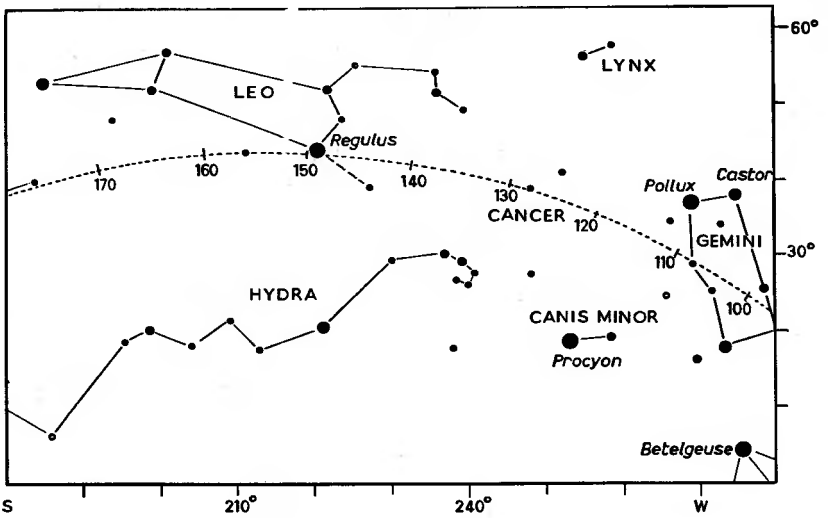
January 6 at	5h	January 21 at	4h
February 6 at	3h	February 21 at	2h
March 6 at	1h	March 21 at	midnight
April 6 at	23h	April 21 at	22h
May 6 at	21h	May 21 at	20h

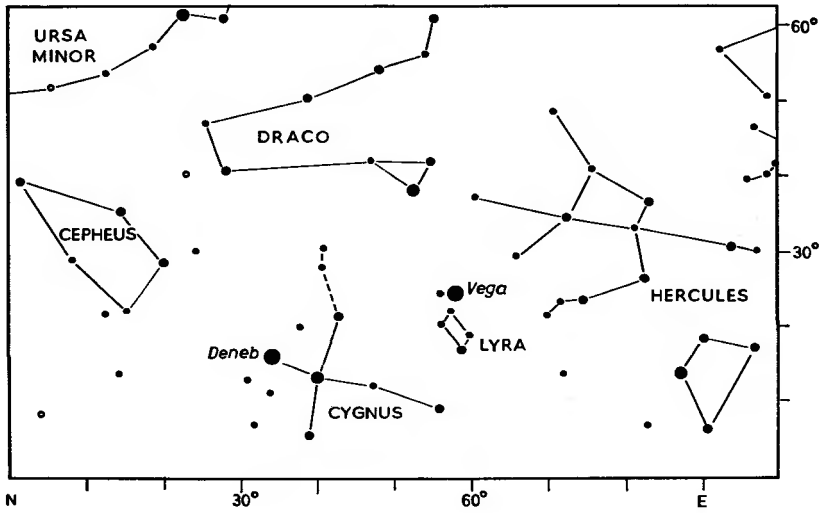




January 6 at 5h	January 21 at 4h
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h

4R





5L

January 6 at 7h	January 21 at 6h
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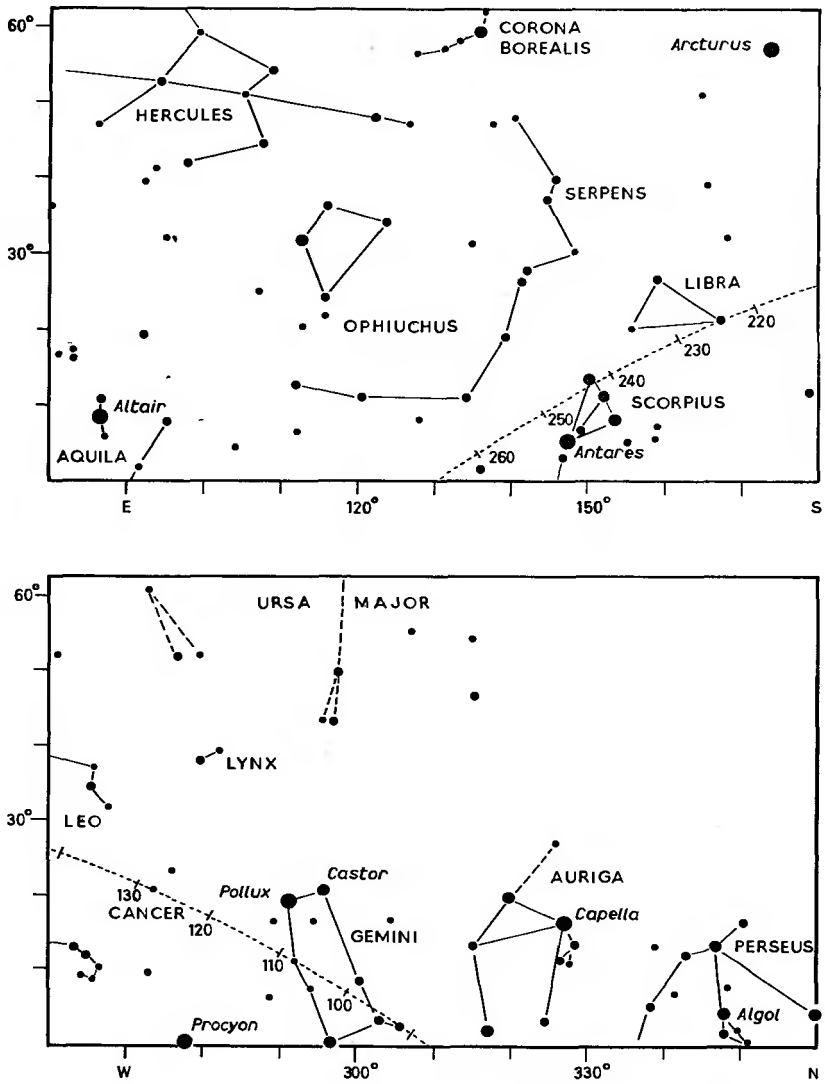
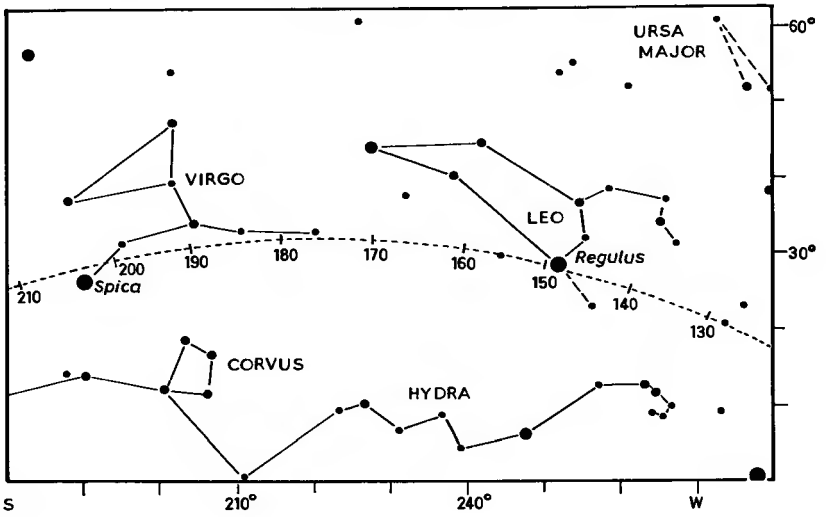
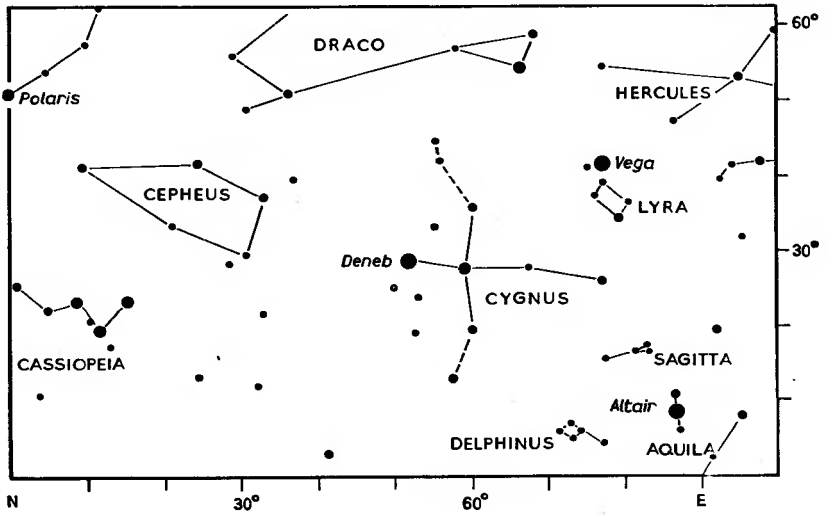
May 6 at 23h	May 21 at 22h



January 6 at	7^h	January 21 at	6^h
February 6 at	5^h	February 21 at	4^h
March 6 at	3^h	March 21 at	2^h
April 6 at	1^h	April 21 at	midnight
May 6 at	23^h	May 21 at	22^h

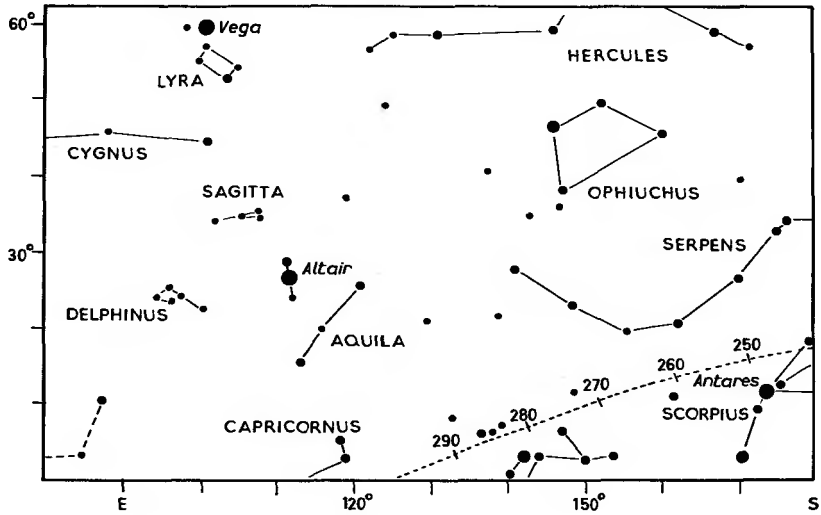
5R

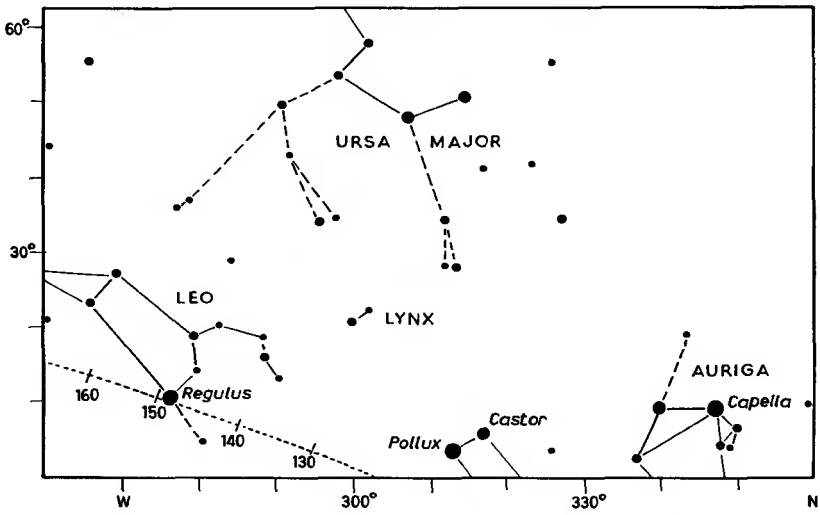




6L

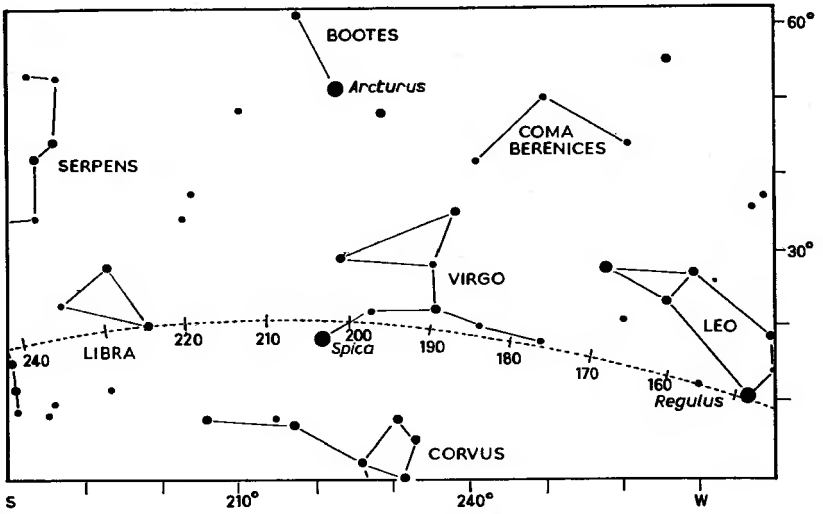
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h

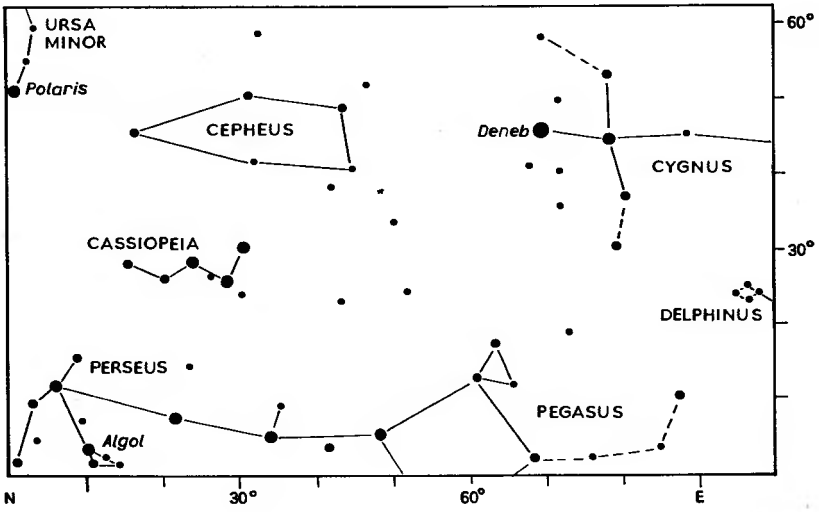




March 6 at	5h	March 21 at	4h
April 6 at	3h	April 21 at	2h
May 6 at	1h	May 21 at	midnight
June 6 at	23h	June 21 at	22h
July 6 at	21h	July 21 at	20h

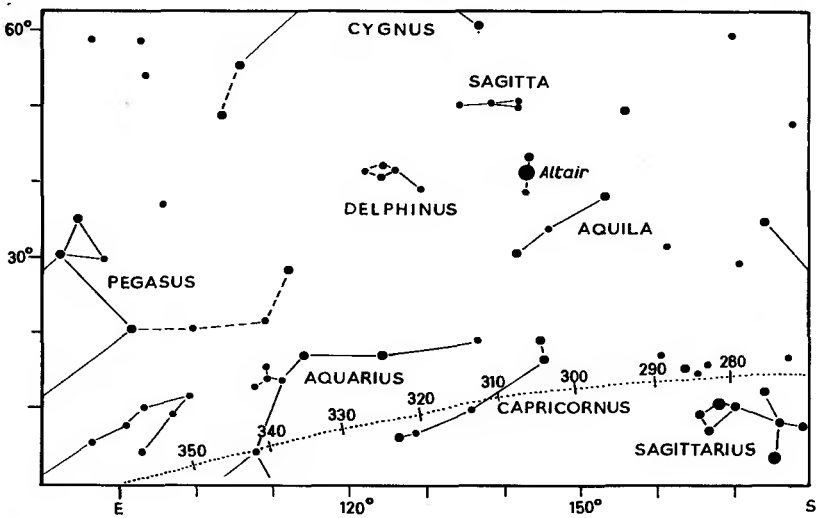
6R

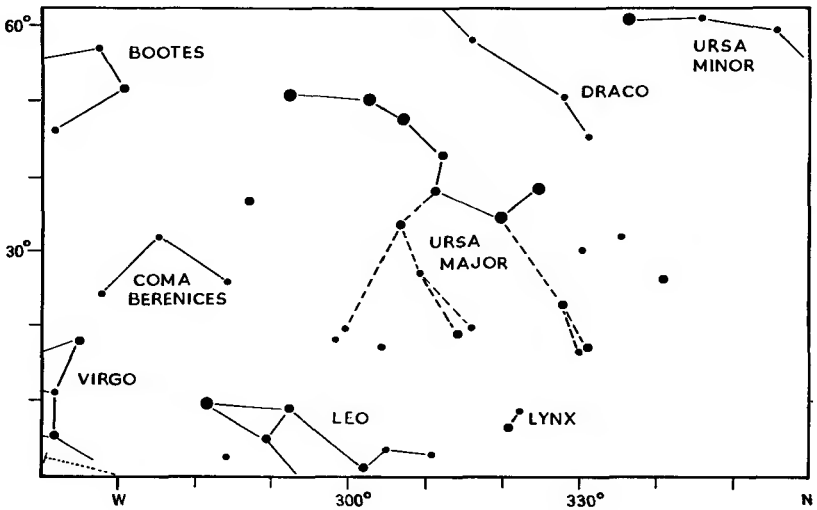




7L

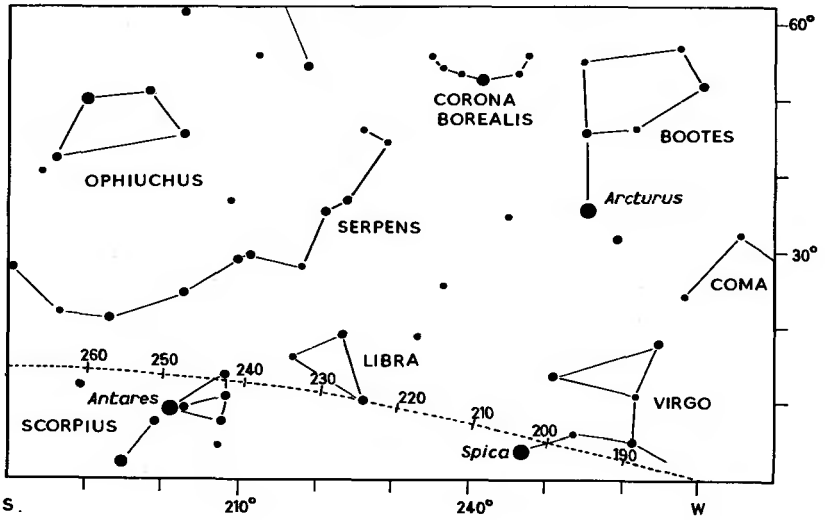
May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

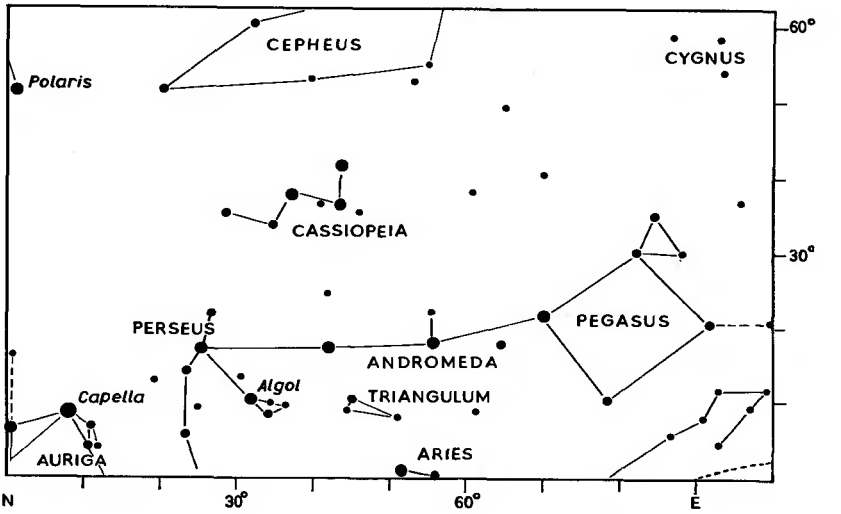




May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

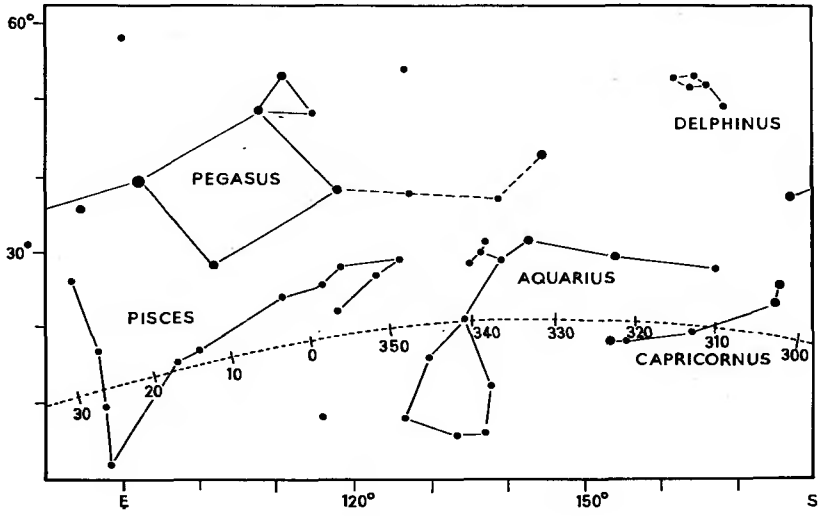
7R

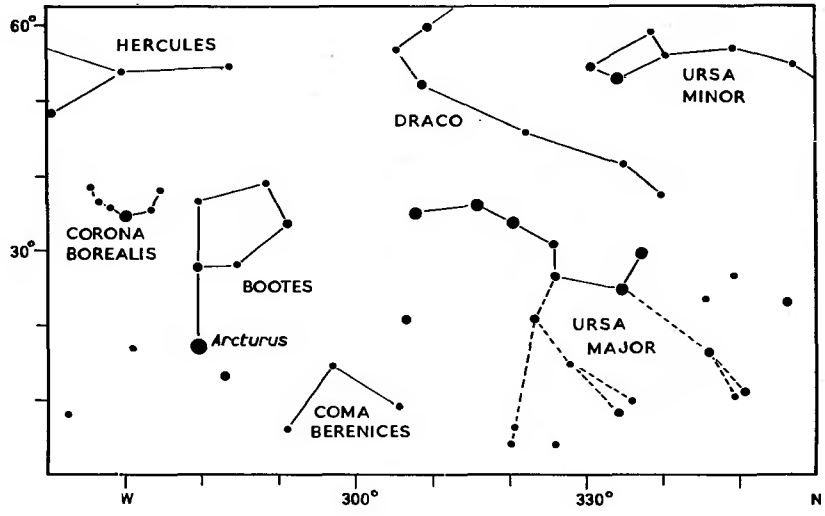




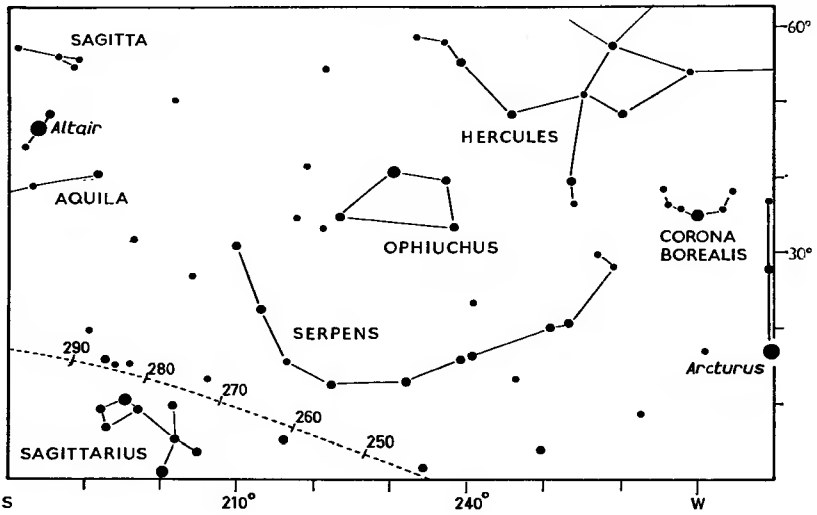
8L

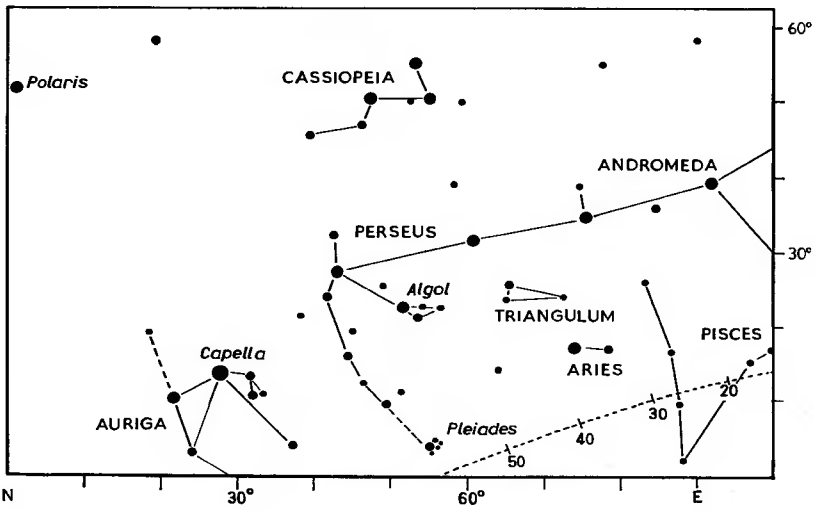
July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h





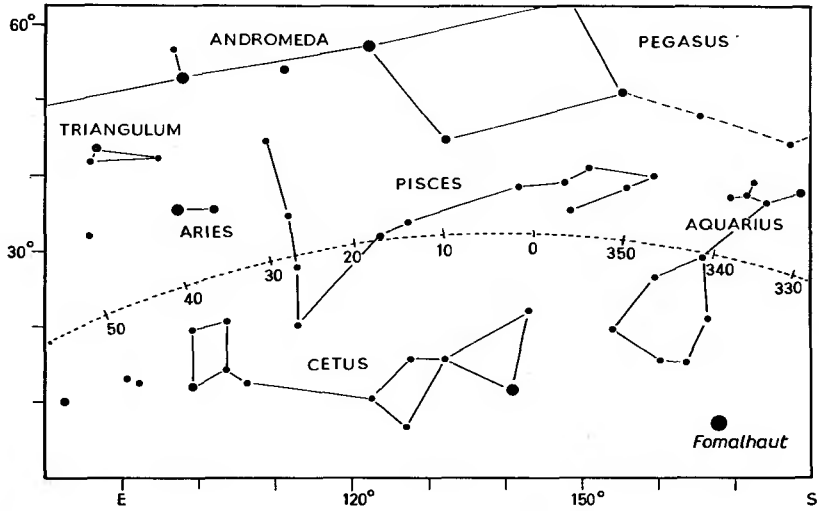
July 6 at 1h	July 21 at midnight	**8R**
August 6 at 23h	August 21 at 22h	
September 6 at 21h	September 21 at 20h	
October 6 at 19h	October 21 at 18h	
November 6 at 17h	November 21 at 16h	

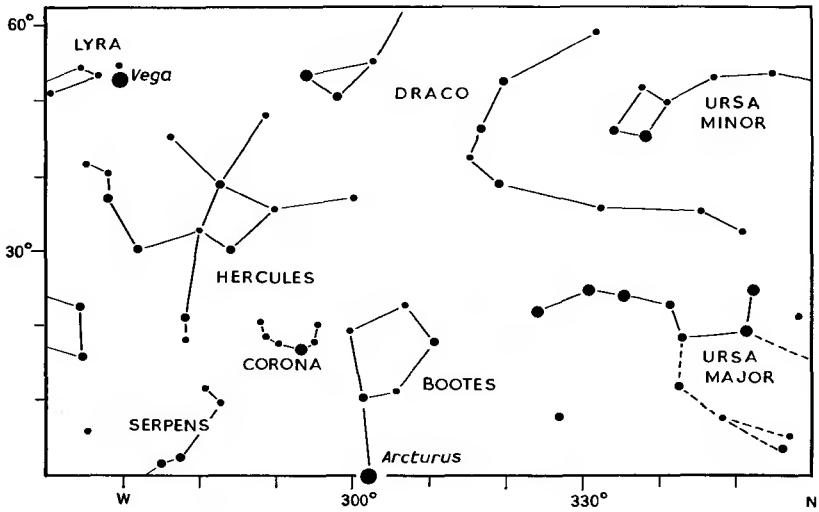




9L

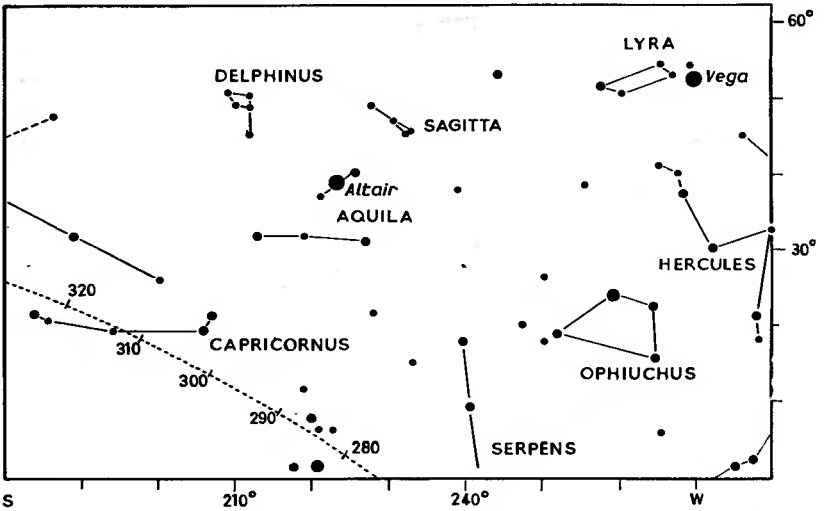
August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h

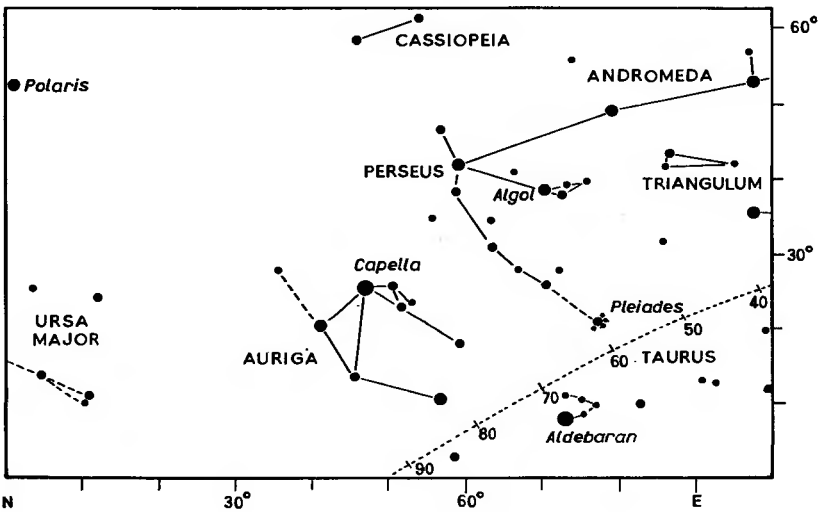




August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h

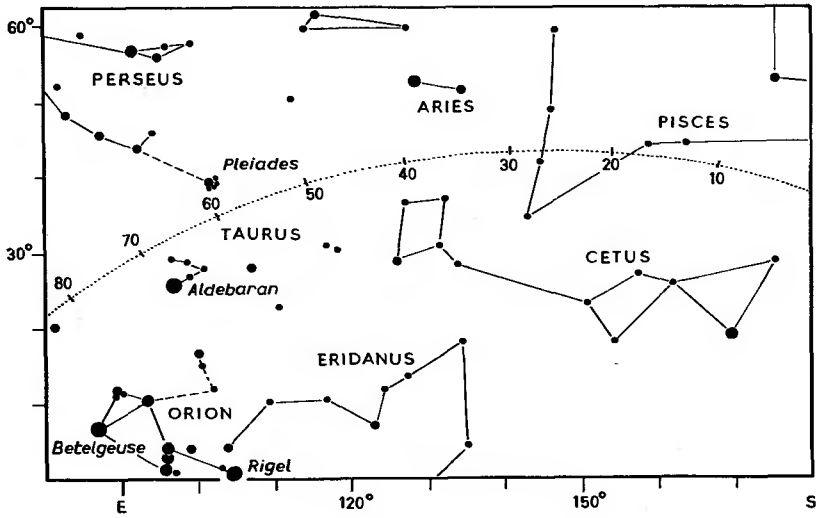
9R

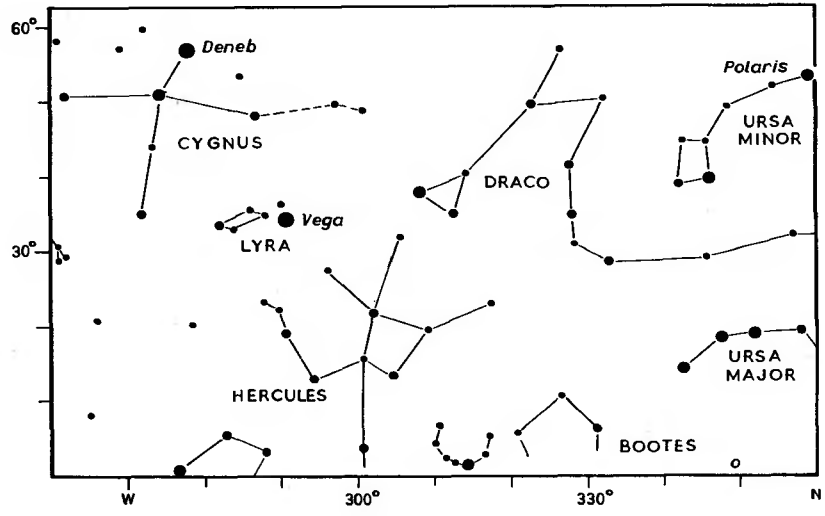




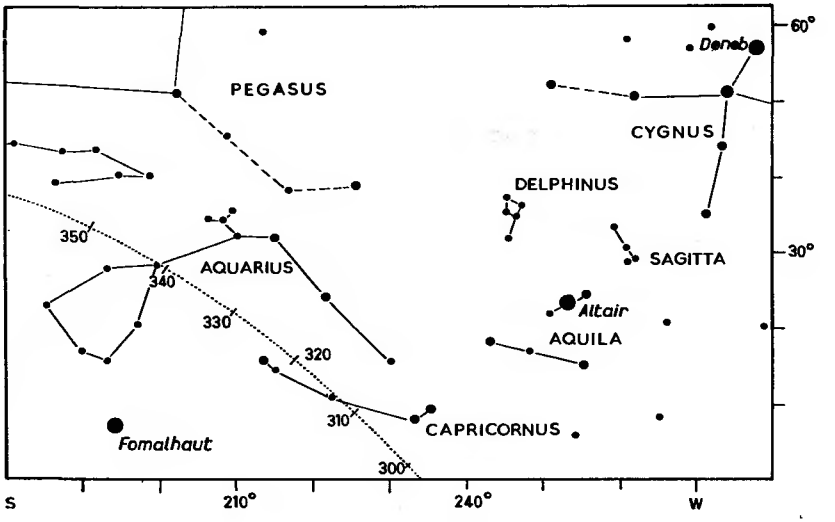
10L

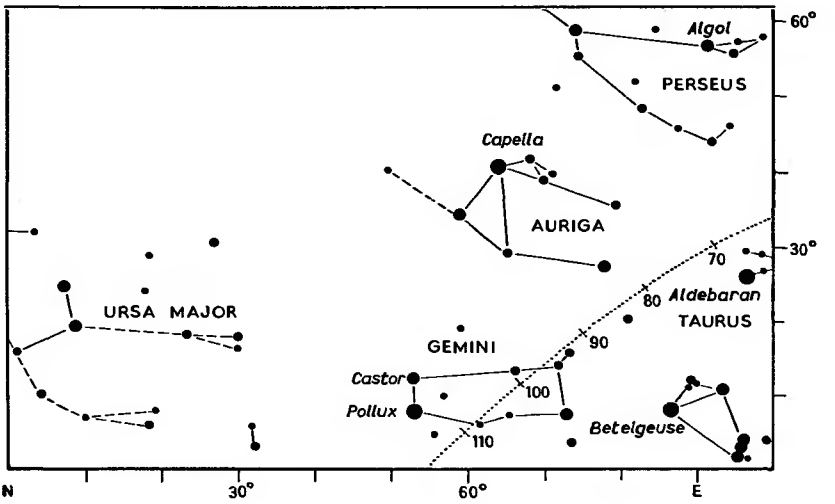
August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h





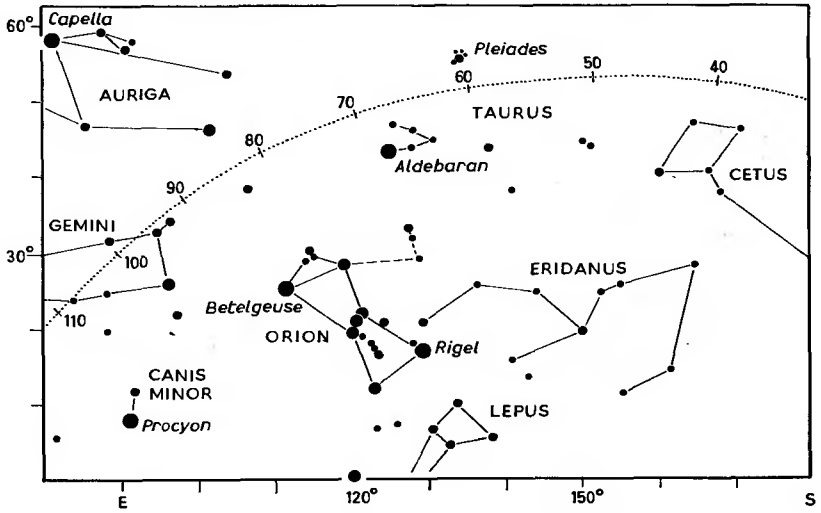
August 6 at 3h	August 21 at 2h	**10R**
September 6 at 1h	September 21 at midnight	
October 6 at 23h	October 21 at 22h	
November 6 at 21h	November 21 at 20h	
December 6 at 19h	December 21 at 18h	

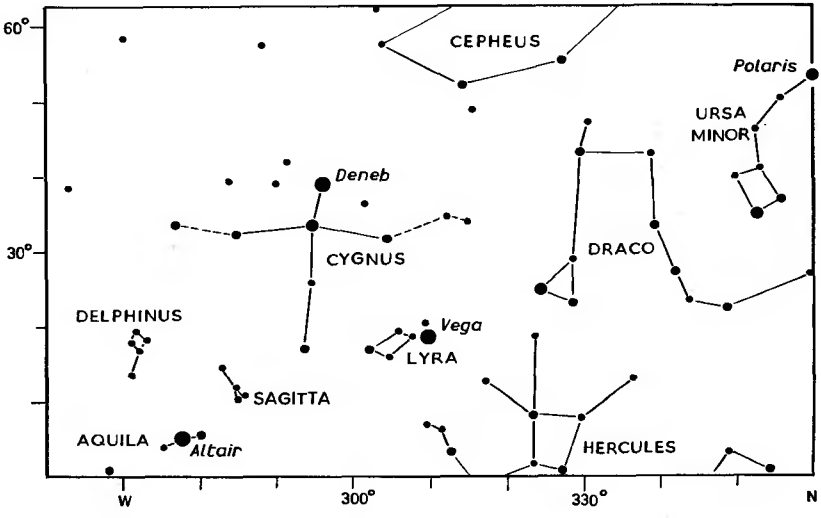




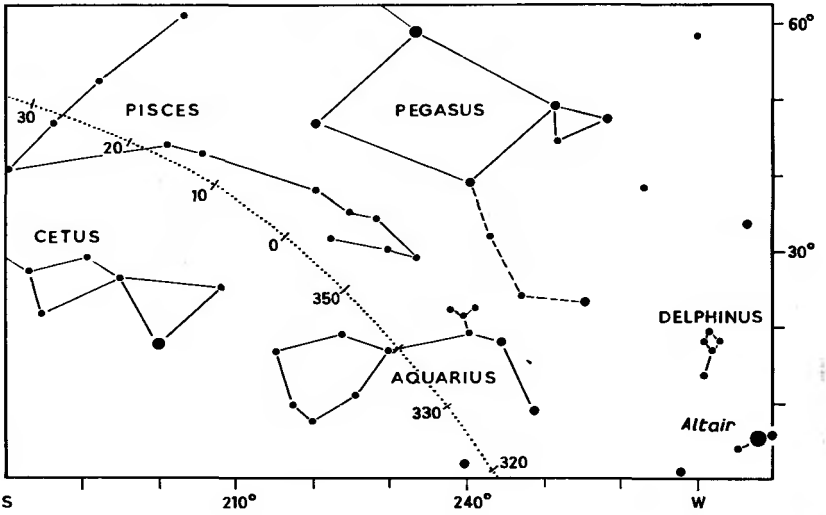
11L

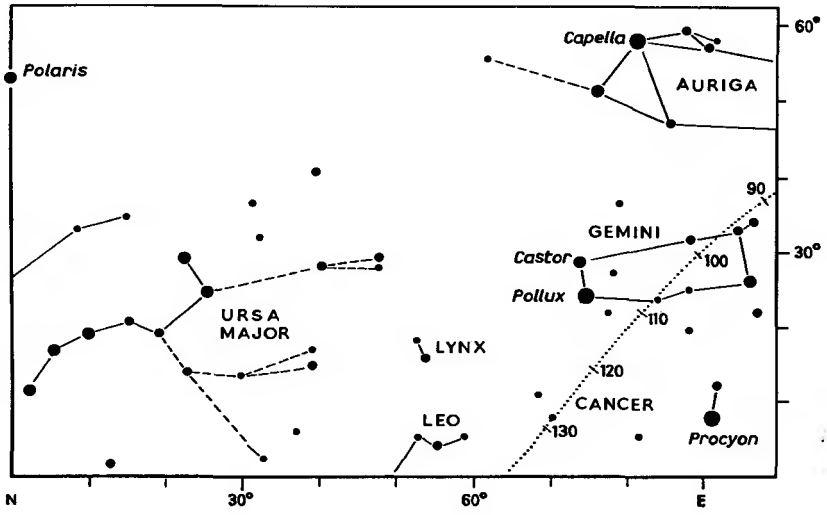
September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h





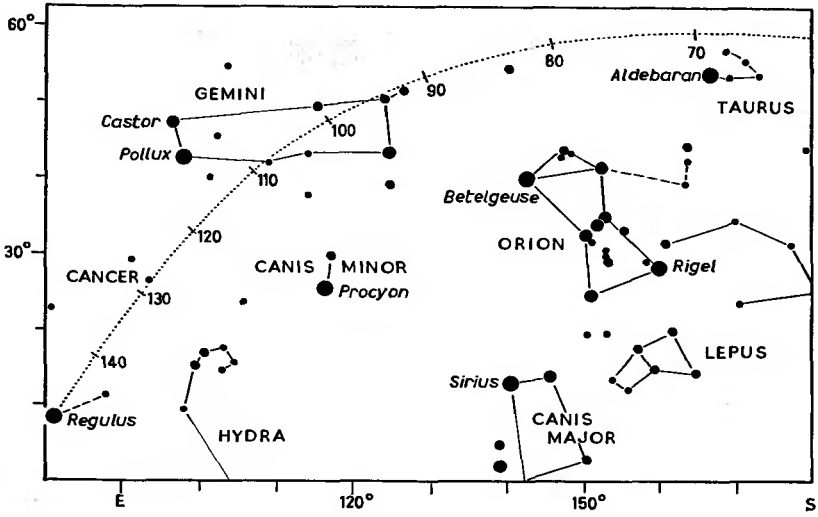
September 6 at 3h	September 21 at 2h	**11R**
October 6 at 1h	October 21 at midnight	
November 6 at 23h	November 21 at 22h	
December 6 at 21h	December 21 at 20h	
January 6 at 19h	January 21 at 18h	

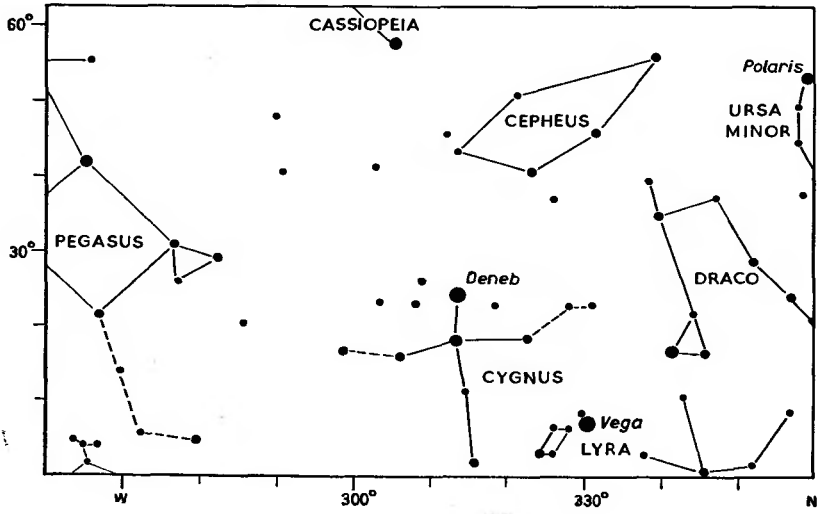




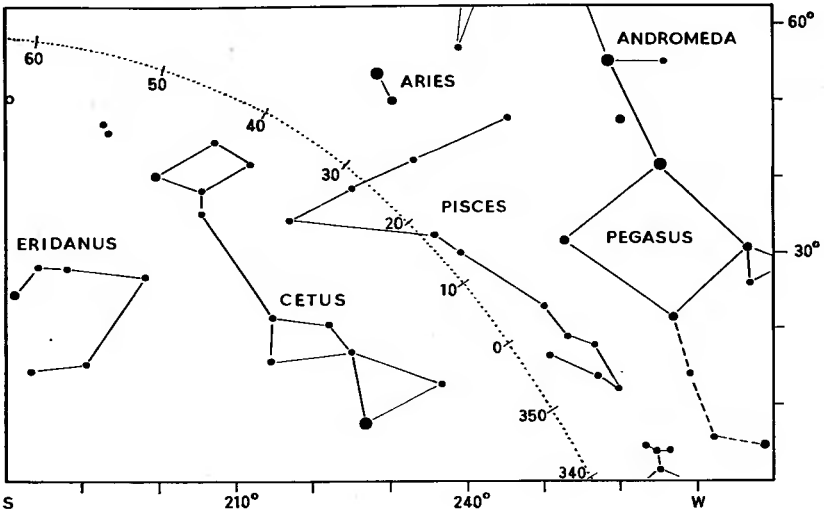
12L

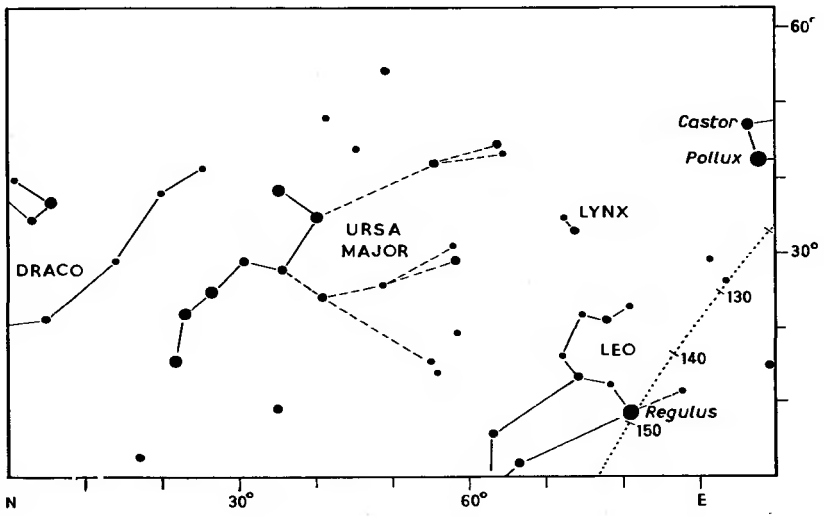
October 6 at 3h	October 21 at 2h
November 6 at 1h	November 21 at midnight
December 6 at 23h	December 21 at 22h
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h

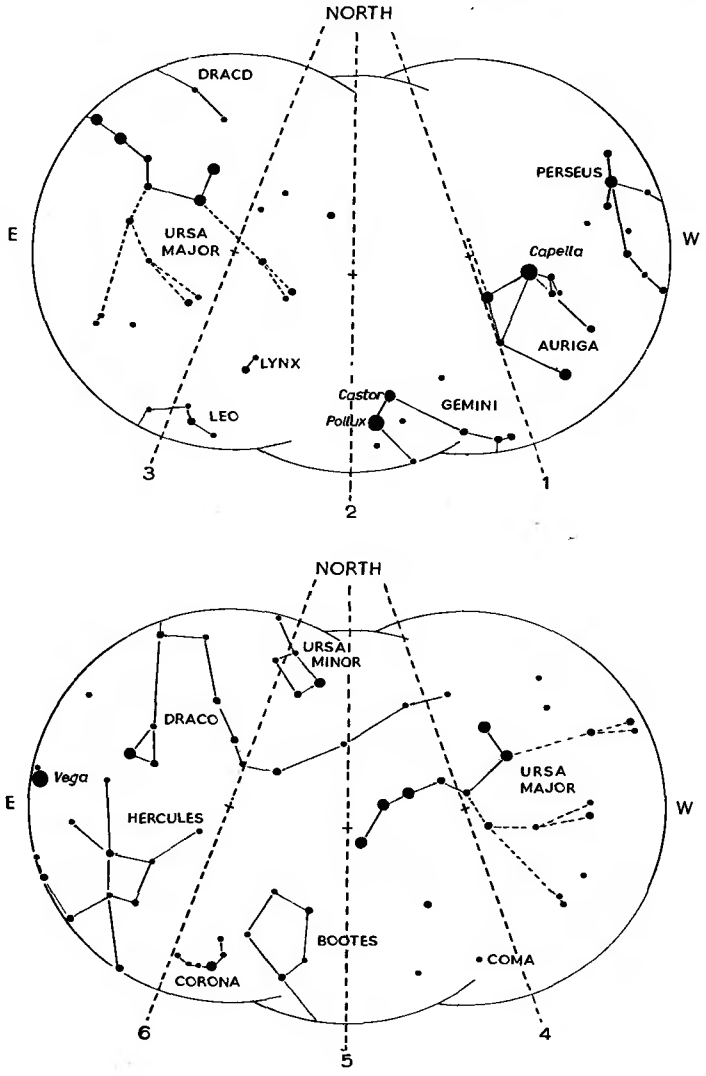




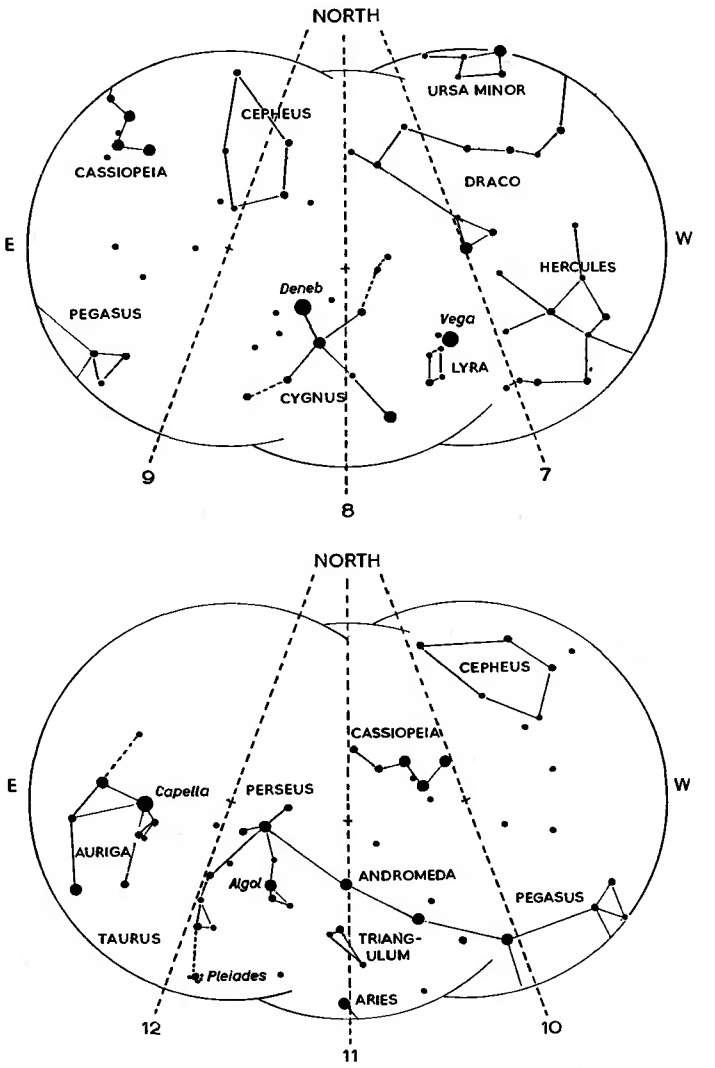
October 6 at 3h	October 21 at 2h	**12R**
November 6 at 1h	November 21 at midnight	
December 6 at 23h	December 21 at 22h	
January 6 at 21h	January 21 at 20h	
February 6 at 19h	February 21 at 18h	







Overhead stars



Overhead stars

The Planets in 1964

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	317°	295°	12°	321°	160°	228°
	21	335°	306°	14°	323°	160°	228°
February	6	355°	319°	16°	325°	159°	228°
	21	12°	331°	19°	327°	159°	228°
March	6	28°	342°	22°	328°	158°	228°
	21	44°	354°	25°	330°	157°	228°
April	6	61°	6°	29°	332°	157°	228°
	21	76°	18°	32°	333°	156°	227°
May	6	88°	29°	36°	334°	156°	227°
	21	96°	40°	40°	335°	156°	227°
June	6	96°	52°	43°	336°	156°	226°
	21	88°	63°	46°	336°	157°	226°
July	6	81°	73°	49°	335°	157°	226°
	21	82°	83°	52°	335°	158°	226°
August	6	90°	94°	54°	334°	159°	226°
	21	102°	104°	55°	333°	160°	226°
September	6	117°	114°	56°	331°	161°	226°
	21	133°	124°	56°	330°	162°	226°
October	6	150°	133°	56°	330°	163°	227°
	21	168°	142°	54°	329°	164°	227°
November	6	187°	151°	52°	329°	164°	228°
	21	206°	158°	50°	329°	165°	228°
December	6	224°	165°	49°	330°	165°	229°
	21	242°	171°	47°	331°	165°	230°
Conjunction:							
Superior		—	Feb. 17	Apr. 22	Feb. 15	Sept. 2	Nov. 9
Inferior		June 19	—	—	—	—	—
Opposition:		—	(1965 Mar.)	Nov. 13	Aug. 24	Feb. 27	May 7

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which this planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What is the bright planet seen to the right of the Pleiades at 1 a.m. (Summer Time) on September 12?*
The time is 0^h G.M.T., and from the table on page 2 the appropriate star chart is found to be number 10. The upper chart on page 22 (10L) shows the Pleiades, and the planet is seen to have a longitude of about 55 degrees. It is then identified from the table opposite as Jupiter.

(2) *Where can Mars be found at the end of October?*
From the table opposite we see that Mars does not come to opposition until 1965, so that it is still a morning star. The same table gives its longitude as about 147 degrees. Using charts 12L or 1L, it is seen that Mars is then near the star *Regulus*, rising in the east an hour or two after midnight, and well up in the eastern sky just before dawn.

Phases of the Moon, 1964

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
Jan.	14	20	43	Jan.	22	05	29	Jan.	28	23	23	Jan.	6	15	58
Feb.	13	13	01	Feb.	20	13	24	Feb.	27	12	39	Feb.	5	12	42
Mar.	14	02	14	Mar.	20	20	39	Mar.	28	02	48	Mar.	6	10	00
Apr.	12	12	37	Apr.	19	04	09	Apr.	26	17	50	Apr.	5	05	45
May	11	21	02	May	18	12	42	May	26	09	29	May	4	22	20
June	10	04	22	June	16	23	02	June	25	01	08	June	3	11	07
July	9	11	31	July	16	11	47	July	24	15	58	July	2	20	31
Aug.	7	19	17	Aug.	15	03	19	Aug.	23	05	25	Aug.	1	03	29
Sept.	6	04	34	Sept.	13	21	24	Sept.	21	17	31	Aug.	30	09	15
Oct.	5	16	20	Oct.	13	16	56	Oct.	21	04	45	Sept.	28	15	01
Nov.	4	07	16	Nov.	12	12	20	Nov.	19	15	43	Oct.	27	21	59
Dec.	4	01	18	Dec.	12	06	01	Dec.	19	02	41	Nov.	26	07	10
												Dec.	25	19	27

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The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer, and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the planetary orbits, and of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The monthly diagrams of the orbits of the planets are intended to give a picture of the way in which the planets move about the Sun during the month. These diagrams are similar to those that were given many years ago in the old *English Mechanic*, and which were also adopted for some time in the *Journal* of the B.A.A. The motions of the planets are all anti-clockwise, and the movement during the month is indicated by the thickened line; the longitudes are measured from the Equinox, marked 0°. It is difficult to show all the orbits to scale, since the distance of Pluto from the Sun is about a hundred times that of Mercury. For this reason, only the orbits of the inner planets (Mercury to Mars) are shown to scale, those of the outer planets being merely suggested in the diagrams. A line drawn from the Earth to any other planet will give a rough idea of the apparent longitude of that body, but a more accurate value can be obtained from the table on page 30, and this will enable the position of the planet to be found on the monthly star-charts.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals

between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

			Mercury	*Venus*
Inferior conj.	to	Elongation West	22 days	72 days
Elongation West	to	Superior conj.	36 days	220 days
Superior conj.	to	Elongation East	36 days	220 days
Elongation East	to	Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they

come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1973), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. At present the rings are well open, so that the planet is quite a bright object.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the February, March and May notes.

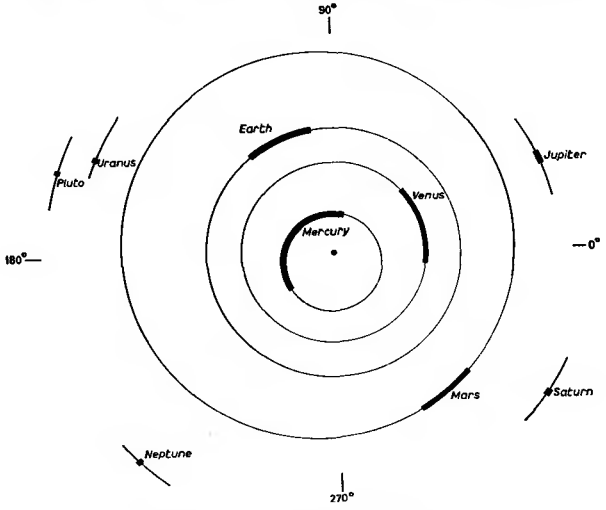
Monthly Notes, 1964

January

New Moon: January 14 *Full Moon:* January 28

Earth is at perihelion on January 3 (nearest to the Sun), its distance from the Sun being then 91,400,000 miles.

Mercury is at inferior conjunction on January 4, and will not be visible for the greater part of the month. It comes to greatest western elongation on January 27 (25 degrees, morning star) and although it is then well south of the Sun, there is just a chance that it may be glimpsed low in the south-east before dawn.

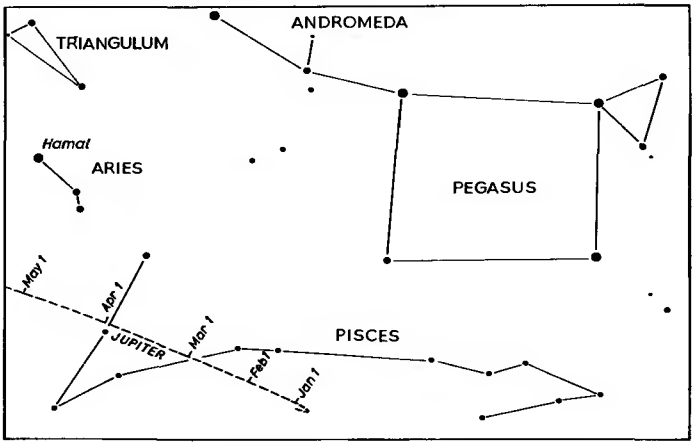


Planetary Orbits in January

Venus is an evening star, and will be a splendid object in the western sky at sunset until the end of May. At the beginning of January it will be low in the south-west, but it moves rapidly north during the month, so that conditions greatly improve, and by the end of January it sets more than three hours after the Sun. On January 9, Venus passes less than a degree south of Saturn, and the two planets may then be seen together in the twilight sky.

A pair of binoculars will be helpful, both planets being seen in the same field of view.

Mars is still theoretically an evening star, but it will not be seen during the month, because it is rapidly approaching conjunction, and it sets only a few minutes after the Sun.



Jupiter, January–May

Jupiter, which was at opposition in 1963 October, is an evening star moving direct among the stars of Pisces. It will be seen in the south at twilight, and it sets about midnight. Its brightness decreases during the month from magnitude −2·1 to −1·9.

Saturn is an evening star in Aquarius, but it is approaching conjunction and its period of visibility after sunset is rapidly decreasing. It should be possible to find the planet, during the first half of the month, low in the south-west for a short period after dark. The conjunction of Mars and Saturn on January 9 is mentioned in the notes on Mars above.

A partial eclipse of the Sun takes place on January 14, but is only visible in Antarctica (see page 72).

Leap Years. Our present calendar (the Gregorian calendar) is a modification, introduced by Pope Gregory XIII in 1582, of the calendar instituted by Julius Caesar. In this calendar every

fourth year was a leap year, but in the course of fifteen centuries the error had accumulated so that the date of the equinox (which controls the date of Easter) was 10 days out. By the time the calendar was used in England in 1752 the error was 11 days. The rule for leap years in the Gregorian calendar is simple enough: the extra day at the end of February is added if the year is divisible by 4, except in the case of century years, ending in 00, which are only leap years if the year is divisible by 400. More simply, it is a leap year if the last two figures divide by 4, but if these two figures are zeroes, then the first two figures must divide by 4. Thus the year 1900 was not a leap year, but the year 2000 will be. The effect of this rule is that in a period of 400 years there are 97 leap years of 366 days, and 303 common years of 365 days, making a total of 146,097 days. The average length of the year over this period is therefore 365·2425 days, which is 0·000305 day longer than the tropical year (the period of revolution of the Earth from equinox to equinox). The error after 400 years will amount to about 3 hours, and it will be over 3,000 years before the calendar is a whole day in error.

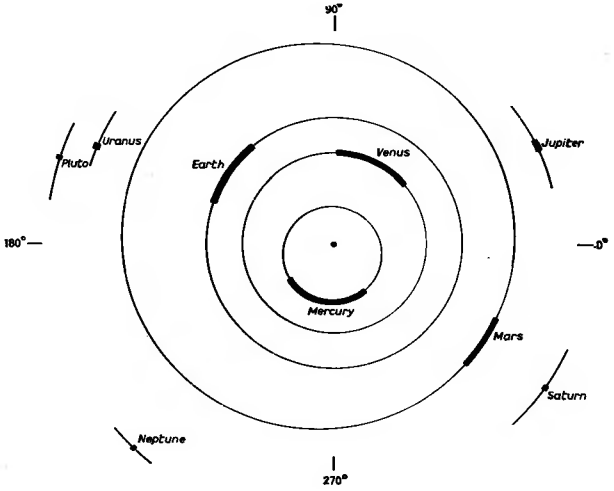
Galileo Galilei. In 1964 we shall be celebrating the fourth centenary of the birth of Galileo, the great Italian scientist, who was born on 1564 February 18. Galileo is remembered in astronomy mainly because of his discoveries with the telescope. He was the first to see the four great satellites of Jupiter, the mountains on the Moon, the starry structure of the Milky Way, and the phases of Venus, while he shares the credit for the discovery of spots on the Sun. Yet these discoveries, important though they were, do not reflect the real greatness of Galileo, for it was his method of dealing with scientific problems that makes his work of such outstanding value. His results were based on experimental evidence, and if he was not the first to use the experimental method, he was certainly a pioneer in presenting those results to the people. He was a public figure, and, forsaking the Latin of his predecessors, he stated his conclusions in the language of his day, bringing science out into the light for all to see.

February

New Moon: February 13 *Full Moon:* February 27

Mercury is now moving in to superior conjunction, and will not be visible during the month.

Venus continues to be seen as a brilliant evening star, setting about four hours after the Sun at the end of the month. The planet is now well north of the Sun, and this will be noticed as it sets in the west. The young crescent Moon will be seen near Venus each month, but on each of these occasions (e.g. February 16, March 17, April 15) the planet will be well to the north of the Moon. Venus will be seen near Jupiter on the nights of February 27 and 28.



Planetary Orbits in February

Mars is at superior conjunction on February 17, and will not be visible during the month. It will be seen from the diagram of the planetary orbits that at the time of conjunction Mars is near perihelion, at a distance of 129 million miles from the Sun.

Jupiter is a bright evening star in Pisces, and will be seen to the

left of the Great Square of Pegasus as that star-group sets in the west. Jupiter will be near Venus at the end of the month, but the two planets are easily distinguished, Venus being much the brighter (Venus, magnitude −3·6, Jupiter −1·7).

Saturn, now on the far side of its orbit (see diagram above), is at conjunction on February 15, and will not be visible during the month.

Uranus is at opposition on February 27, when it may be found in the constellation Leo (see diagram, page 64). The magnitude of the planet at this time is +5·7, and it should just be possible to see it with the naked eye; in a small telescope it appears as a greenish disk. The distance of Uranus at opposition is about 1,610 million miles from the Earth.

The Sundial. At this time of year – and again in November – a sundial will be found to be about a quarter of an hour in error as compared with a clock. The difference is a demonstration of the fact that the true Sun is not a good timekeeper; it does not travel uniformly round the sky, whereas our clocks keep mean time, that is, they maintain a uniform average rate which, over the years, matches the motion of the true Sun. The difference between apparent time (as told by the Sun), and the mean time of our clocks is called the equation of time. It may be either positive or negative, that is, the sundial may be either slow or fast as compared with a clock keeping mean time. A sundial will be found to be about 14 minutes slow in February, while in late October and early November it will be as much as 16 minutes fast. The equation of time is zero on four occasions during the year – about April 15, June 13, September 1 and December 25, and only on these four days is the Sun due south at noon.

The variations in the rate at which the Sun appears to travel are due to two effects. First, the Sun does not travel round the equator (along which we measure longitude and intervals of time), but round the ecliptic; and secondly, the Earth's orbit is not circular but is an ellipse, and the Sun is nearest to us (and

therefore travelling most rapidly) at the beginning of January. Each effect causes a displacement of the Sun's position, and this displacement goes through a complete cycle of changes in the course of the year. The sum of the two effects is the equation of time, which vanishes on the four dates already mentioned, and has four maximum values: -14^m about February 12, $+4^m$ on May 14, -6^m on July 27 and $+16^m$ on November 3. The cycle then starts again, and it will be noticed that the interval between the two largest maxima, on November 3 and February 12, is only three months; during this period the equation of time is changing most rapidly, and about December 23 it is altering by as much as half a minute a day. The effect of this on the times of sunrise and sunset is mentioned in the note on page 71.

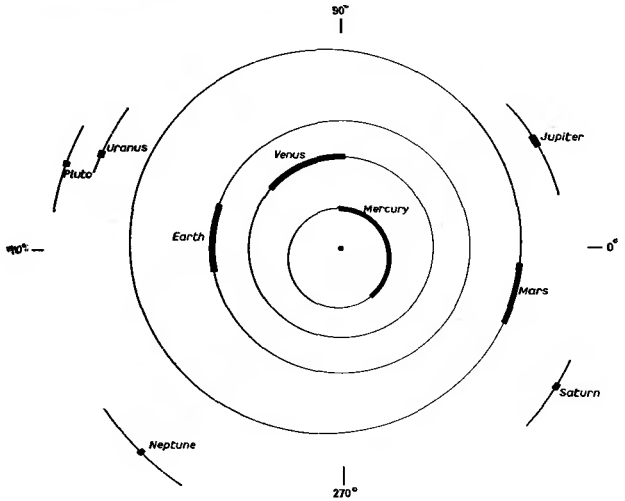
Whatever the design of a sundial, the essential part of the instrument is the straight edge or gnomon which casts the shadow. This gnomon is erected so as to be parallel to the Earth's axis, that is, the angle of the gnomon must equal the latitude of the place. It follows that an accurate sundial must be designed to suit its situation – one cannot buy a sundial at a super-market! The dial on which the shadow of the gnomon is cast is usually horizontal, but may be vertical or inclined, or even part of a circular arc. The assumption is made that the Sun is due south at noon, so that the 12-hour mark is measured due north, and the other hours are marked off east and west at the rate of 15 degrees for each hour. It can scarcely be said that the sundial is a useful instrument, but there is a certain romantic charm about an old sundial, and many of them are provided with mottoes, witty, wise, or merely humorous. The late Hilaire Belloc provided a number of suitable mottoes for sundials, but perhaps the most pointed of these is the simple rhyme

I am a sundial, and I make a botch
Of what is done far better by a watch.

March

New Moon: March 14 *Full Moon:* March 28
Equinox: March 20

Mercury is at superior conjunction on March 13, and for the greater part of the month will remain invisible. Towards the end of March, however, it moves out again from the Sun to become an evening star, and there is a chance of seeing this elusive planet in western sky after sunset. (See notes and diagram on page 45). On March 31, Mercury is 3 degrees north (i.e. above and to the right) of Jupiter, but there is little risk of confusion, as Jupiter is so much the brighter of the two.



Planetary Orbits in March

Venus now grows noticeably brighter as an evening star, and sets more than 4 hours after the Sun. At the equinox, when the Sun is on the equator, Venus is 18 degrees north and 45 degrees east of the Sun.

Mars has now passed conjunction, and is theoretically a morning

star. It moves out from the Sun very slowly, and by the end of March it is still only 9 degrees west of the Sun, so that it will not be seen during the month.

Jupiter is still an evening star, but its period of visibility after sunset grows shorter, and by the end of the month it sets a little north of west about 1½ hours after the Sun.

Saturn now becomes a morning star, but is not likely to be seen until the end of March, when it rises to the south of east about an hour before the Sun.

Pluto is at opposition on March 3; it is in Leo, appearing as a faint star of the fifteenth magnitude.

Equinoxes and Solstices. It will be noticed that the equinox occurs this year on March 20, and this may seem to many readers to be rather earlier than usual. The date of an equinox is not rigidly fixed – it is defined as the time at which the Sun reaches the First Point of Aries, i.e. when its longitude is 0 degrees. Since the actual period of revolution of the Earth with respect to the equinox is 365·2422 days, the date of the equinox moves forward each year by the odd 0·2422 day (about 6 hours), and drops back a day in leap years. This applies equally to the other equinox and to both solstices, all of which show the same behaviour—advancing by about 6 hours in common years, and falling back by about 18 hours in leap years.

	Equinoxes				*Solstices*			
	d	h	d	h	d	h	d	h
1958	Mar. 21	03	Sept. 23	13	June 21	22	Dec. 22	09
1959	21	09	23	19	22	04	22	15
1960	20	15	23	01	21	10	21	20
1961	20	21	23	07	21	15	22	02
1962	21	02	23	13	21	21	22	08
1963	21	08	23	18	22	03	22	14
1964	20	14	23	00	21	09	21	20
1965	20	20	23	06	21	15	22	02

It will be seen that the earliest dates are always in leap years, and that the dates repeat themselves very closely every 4 years,

although there remains a small error which accumulates. As a result, the dates move slowly backwards throughout the 400-year cycle of the Gregorian calendar. By the year 2000 the date of the equinox will be March $20^{d}\ 07^{h}$, but the year 2000 is a leap year, and the dates will continue to move back, until 2096, when the equinox will be on March $19^{d}\ 14^{h}$.

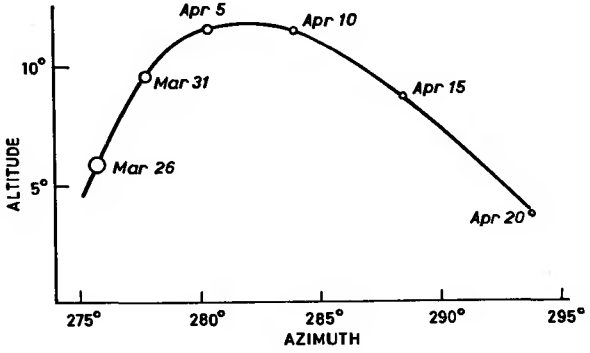
The birthplace of stars. The stars of Orion are of a hotter and whiter type than our Sun, but there are two notable exceptions. *Betelgeuse*, 'the shoulder of the giant', is slightly red in colour and its light varies in an irregular manner. It is red because it is at a lower temperature than the Sun, yet it gives out 10,000 times as much light. This is a giant star, at least 300 times as big as the Sun, and if our Sun were as big as this it would extend beyond the orbit of Mars. The star *Rigel*, on the other hand, although not so huge, is at least 20,000 times as luminous as our Sun. Now, if a star of this size is pouring out light and heat at this astonishing rate, it obviously cannot last very long. The Sun, which is believed to be at least 3,000 million years old, is still going strong, and promises to do so for many millions of years. But *Rigel* could not possibly maintain its present output of energy for more than a few million years. The conclusion is obvious – that *Rigel* is much younger than the Sun, and therefore that stars must have been formed at different times in the past – perhaps they are still being formed.

There is an increasing amount of evidence that this is indeed the case, and that stars are born in the vast clouds of dust and gas that occur in the spiral arms of our Galaxy, in regions such as the great nebula in Orion. Some years ago a photograph showed five small areas of glowing nebula in one part of this area. A more recent photograph of the same region showed seven glowing spots, so that something must be happening here, and it is tempting to conclude that we are witnessing the formation of two new stars. At any rate, there is no doubt that the evolution of stars is a continuous process, not only in our own Galaxy, but in thousands of millions of other galaxies throughout the universe.

April

New Moon: April 12 *Full Moon:* April 26

Mercury is at greatest eastern elongation on April 7 (19 degrees; evening star), and will be favourably placed for observation at the beginning of the month in the western sky just after sunset. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings at a time when the Sun is 6 degrees below the horizon; this will be about 35 minutes after sunset at this season.

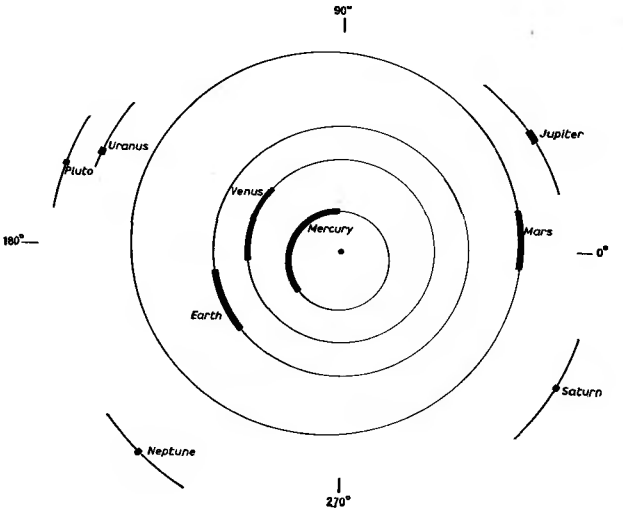


Mercury, April

The sizes of the circles give an approximate indication of the expected brightness of the planet; it will be noticed that Mercury is much brighter before the date of greatest elongation. There is a possibility of confusion with the planet Jupiter, which is in the same part of the sky, but is very much brighter than Mercury, and several degrees nearer to the horizon.

Venus is also at greatest eastern elongation this month (46 degrees from the Sun on April 10), and is in high northern declination, so that it presents a splendid appearance for several hours after sunset. At the end of the month it will be almost midnight before Venus sets, at a point well north of west. At the beginning of the

month the planet passes just south of the Pleiades, and on April 14 will be seen some degrees north of *Aldebaran*.



Planetary Orbits in April

Mars is a morning star, but rises only a few minutes before the Sun at the end of April.

Jupiter is in conjunction with the Sun on April 22, but it may be possible to see the planet for a short while in the first few days of the month, in the west in the evening twilight.

Saturn now begins to appear as a morning star, rising in the south-east among the stars of Aquarius.

The motion of the planets. In general, the planets move to the left across our sky, but this motion is not a continuous one, like that of the Sun and Moon. These two bodies always move eastwards in this way (this is direct motion), but the planets behave differently, for at certain definite intervals they pause and go backwards for some distance (this is retrograde motion), making a loop in the

sky. The effect is very much the same as watching a race from the grandstand; the runners pass in front of you, moving to the right, but as they round the bend, they are moving away from you, and on the other side of the track they are moving to the left. If the Earth stood still in space, this is all that would happen. We should see Venus, for instance, going round the Sun, just shuttling to and fro, moving to the right in front of the Sun and to the left behind it. But because the Earth is moving, the Sun appears to travel eastwards round the sky, taking Venus with it. Thus the path of the planet is drawn out into a long line with loops in it, each loop representing one revolution of the planet about the Sun.

Now, it is not difficult to realize that if you were standing on the surface of Venus you would see the Earth doing exactly the same things. Each planet sees the other making the same direct and retrograde motions at the same time, but in diametrically opposite parts of the sky. So the behaviour of Mars, Jupiter or Saturn, as we see them from the Earth, is just a copy of the movements of the Earth as they would see them. When planet and Earth are on the same side of the Sun, the apparent motion is retrograde, and the opposition of an outer planet, or the inferior conjunction of an inner planet will occur in the middle of this retrograde movement. When Earth and planet are on opposite sides of the Sun, the motion is direct, and this direct movement takes up much more time than the retrograde one because of the Earth's movement in the same direction as the planet. It can be seen that the nearer the planet comes to the Earth, the larger is the loop in its path, and the faster is its apparent motion. The large loop and the long period of rapid direct motion of Mars are quite characteristic of this planet. The retrograde motion of Mercury and Venus is seldom noticed, because it occurs at the time of inferior conjunction, when these planets are drawing close to the Sun and cannot be observed against the background of stars.

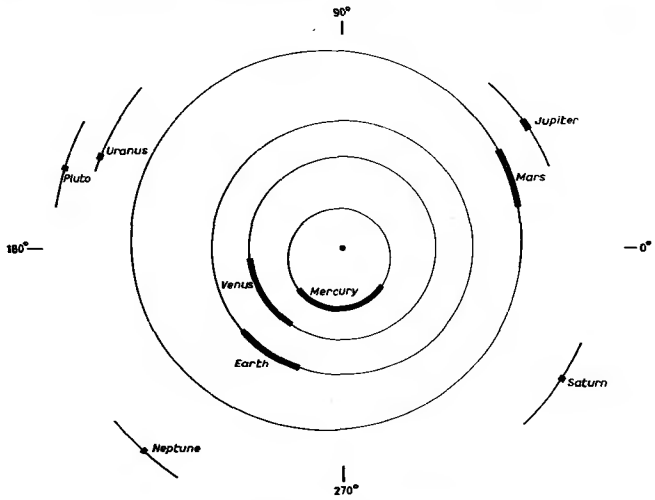
May

New Moon: May 11 *Full Moon:* May 26

Mercury was at inferior conjunction at the end of April, and comes to greatest western elongation on May 24 (25 degrees; morning star). At this time, however, it is well south of the Sun, and is unlikely to be seen in the bright dawn sky.

Venus reaches its greatest brilliancy as an evening star on May 13 (magnitude −4·2). It is now swinging round towards inferior conjunction, and its apparent motion eastwards becomes slower; at the end of May it reaches a stationary point, and then begins to move westwards, and its elongation from the Sun rapidly decreases. As a result, the time of setting becomes earlier each night, and at the end of May, Venus sets only 2 hours after the Sun. In a small telescope the planet shows the crescent phase of a young moon, the horns of the crescent pointing east, i.e. to the left.

Mars is a morning star, but is still too close to the Sun to be readily visible. There is a conjunction with Jupiter on May 19, when the

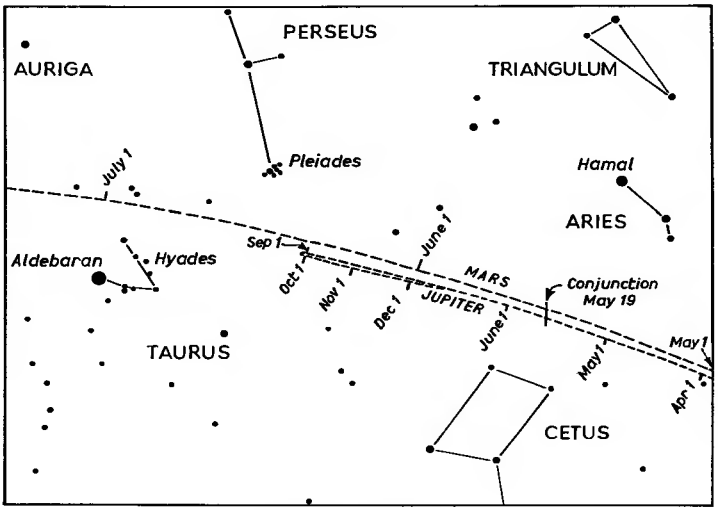


Planetary Orbits in May

two planets will be less than a degree apart. Mercury is also in the same part of the sky, but unfortunately these planets all rise only a few minutes before the Sun, and this interesting configuration is not likely to be seen in northern latitudes.

Jupiter now begins to appear as a morning star, but is unlikely to be seen until the end of the month.

Saturn is a morning star, rising in the south-east about 2 hours before sunrise at the beginning of May. It will be seen among the stars of Aquarius, to the right of the Great Square of Pegasus. The planet is brighter than any other star in the neighbourhood (magnitude +1·1) and this will make it easy to recognize.



Jupiter and Mars

Neptune is at opposition on May 7, and may be found about 2 degrees east and a degree north of the third magnitude star Alpha Librae (*Zuben el Genubi*). Neptune is not visible to the naked eye, but with a small telescope it may be seen as a greenish disk of magnitude +7·7. At opposition, the distance of Neptune from the Earth is about 2,720 million miles.

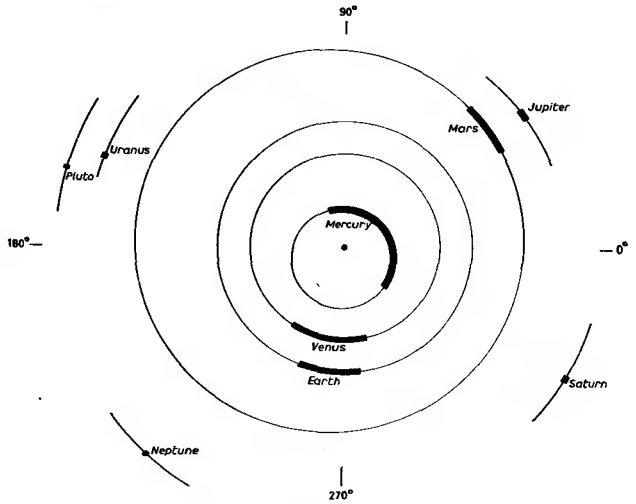
Cassiopeia. On a May night the constellation Cassiopeia will be seen low down near the northern horizon, its very obvious shape (like the letter W) and its bright stars, making it a conspicuous object in this part of the sky. Its position may also help the observer to find the Plough (reversing the usual procedure) for the Plough is on the opposite side of the Pole Star, and at this time is almost directly overhead in a most unfamiliar position. Cassiopeia is full of interesting objects, for the greater part of it is immersed in the Milky Way. It was in this constellation that Tycho Brahe observed the brilliant supernova of 1572 – one of the three supernovae which have been recorded in our Galaxy. The new star, which was as bright as the planet Venus, and was even visible in daylight, was the subject of much speculation. The scientists of the day adhered to the teachings of Aristotle, who had maintained that in the starry sphere everything was eternal and unchanging. This could not be a comet, for it did not move among the stars. Was it then some condensation of fiery vapours in the upper air? To these questions Tycho, then a young man of 26, gave a scientific answer. He repeatedly measured the position of the star, with reference to the other stars of Cassiopeia and to the Pole Star, and showed that the nova did not change its position in the slightest, whether Cassiopeia was in the zenith or low down on the northern horizon. If the star had been as near as the Moon it would have shown a parallax of at least a degree, that is, it would have appeared one degree lower (with respect to the neighbouring stars) in the sky when it was low in the north. So the star must have been at a distance greater than the Moon, and, in spite of Aristotle, there were changes taking place in the Universe. The new star finally disappeared from view in 1574, and today there is no visible object in its place. Radio astronomers, however, have detected a faint radio source in this position. It is interesting to note that in another part of Cassiopeia lies the most powerful of all radio sources, called Cassiopeia A, and this, too, appears to be the remnants of a supernova, although it is at a much greater distance, and its appearance was not recorded.

June

New Moon: June 10 *Full Moon:* June 25
Solstice: June 21

Mercury is moving towards superior conjunction on June 27, and will not be visible during the month.

Venus is at inferior conjunction on June 19, and rapidly disappears from view as an evening star. It reappears just as rapidly in the dawn sky as a morning star at the end of June. At the conjunction on June 19, Venus is only 27 million miles from the Earth.



Planetary Orbits in June

Mars is a morning star, but emerges only slowly from the Sun's rays; it rises about an hour before sunrise at the beginning of June, and about 2 hours before the Sun at the end of the month. Its magnitude is +1·6, and it moves from Aries into Taurus, being seen between the Pleiades and the Hyades about June 20.

Jupiter is a morning star and may be seen in the east before dawn. The planet is in the constellation Aries and is moving eastwards

towards the star-clusters Hyades and Pleiades. At the end of June, Jupiter rises about 3 hours before the Sun; its magnitude is then +1·7.

Saturn is a morning star, rising about midnight in the south-east. The planet reaches a stationary point on June 16 and then begins its retrograde movement (see diagram on page 58). Magnitude +1·0.

A partial eclipse of the Sun on June 10 will be visible only in Australasia.

A total eclipse of the Moon on June 24–25 will be visible in the British Isles. It begins about an hour before midnight (see details on page 72) and becomes total about a quarter of an hour after midnight. Total eclipse lasts until $1^h\,57^m$ on June 25, and the eclipse ends at $3^h\,03^m$.

Parallax. No two people ever see the Moon in exactly the same place in the sky, the change in position from one observer to the other causing a change in the apparent position of the Moon, which is near enough to the Earth to show a large parallax. The positions of the Moon which are given in the tables are calculated for an observer at the centre of the Earth, but at any other point on the Earth's surface, the apparent position of the Moon will be different. The maximum value of the parallax is nearly a degree when the Moon is on the horizon, but the parallax of more distant objects is much less; it amounts to a few seconds of arc for the Sun and the planets, and is quite unmeasurable for the stars. We therefore measure the parallax of the stars in a different way, using the radius of the Earth's orbit as a base-line. For members of the solar system, however, the parallax is quite measureable when the equatorial radius of the Earth is taken as the base-line. The angle subtended at the distant body by the Earth's equatorial radius is then called the equatorial horizontal parallax (because it is the maximum value of the parallax, observed when the body is on the observer's horizon). The horizontal parallax of the Sun (called the solar parallax) is $8''{\cdot}79$, and the parallaxes of the planets are found simply by dividing this figure by the distance of the planet; the

values may therefore range from about 30″ for Venus when at its nearest to us, to the quarter of a second for Pluto. By contrast the parallax of the Moon is quite large, and it cannot be calculated in any such simple manner. The average value is 57′, and since the effect of parallax is always to displace the body vertically downwards towards the horizon, this is the average amount of the depression of the Moon when it is on the horizon. As a result, this amount has to be included in calculations of the times of moonrise and moonset. Similarly this large correction must be included in calculations of eclipses or occultations, which can become very troublesome in border-line cases, as when the observer is near the edge of the shadow in a solar eclipse (i.e. near the edge of the eclipse track across the Earth) or is observing an occultation in which the star just grazes the limb of the Moon.

In the case of a satellite which is nearer to us than the Moon, the parallax can be very large indeed. Some of the natural satellites show this very well, perhaps the best example being Phobos, the inner satellite of Mars. This little body revolves about the planet at a distance of 5,800 miles, so that it is only about 3,700 miles from the surface of Mars. Its parallax is as much as 21 degrees, and this means that Phobos is invisible from any place at latitudes greater than 69 degrees. Some of the artificial satellites of the Earth are even closer than this, and a satellite at a height of 1,000 miles above the Earth's surface will have a parallax of about 53 degrees. If it travelled in an equatorial orbit, it would only be visible in a broad belt stretching 37 degrees north and south of the equator. It is for this reason that the satellites are usually launched in an inclined orbit, so that they may be visible over the greater part of the Earth.

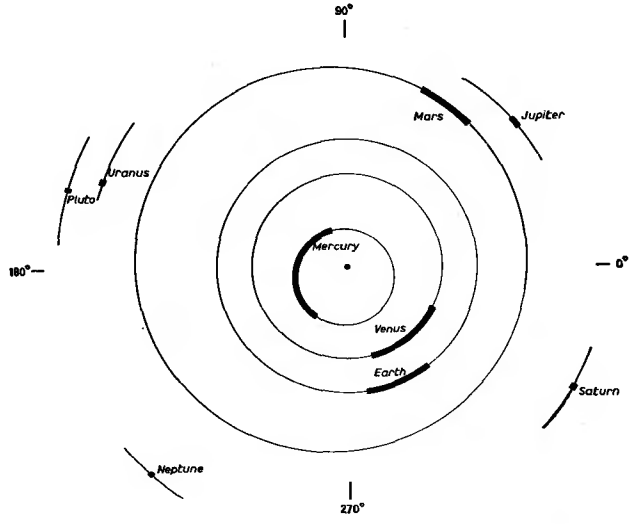
July

New Moon: July 9 *Full Moon:* July 24

Earth is at aphelion (farthest from the Sun) on July 5, its distance from the Sun being then about 94,500,000 miles.

Mercury was at superior conjunction at the end of June, and will be too close to the Sun to be seen during the month of July.

Venus moves rapidly out from the Sun to become a brilliant object in the morning sky. It is again at greatest brilliancy on July 26 (magnitude −4·2), and at this time it may be seen in a small telescope as a small crescent moon, with the horns of the crescent pointing to the west. On the morning of July 18, Venus will be found to be about 5 degrees south of Mars, but it is more than 100 times as bright as that planet (Venus, magnitude −4·1, Mars +1·7).



Planetary Orbits in July

Mars is a morning star moving direct in Taurus. On July 1 it passes about 6 degrees north of *Aldebaran* (magnitudes: Mars +1·6,

Aldebaran +1·1), and on July 18 it will be 5 degrees north of Venus. On this occasion, the apparent motion of Mars is actually greater than that of Venus, but this state of affairs does not last very long, and Venus will soon catch up with Mars, and pass that planet in August. At the end of July, Mars rises about 3 hours before sunrise.

Jupiter is a bright morning star (magnitude −1·7 to −1·9) moving direct in Aries. At the end of the month the planet rises at midnight and passes into the constellation Taurus.

Saturn now rises well before midnight, and will be seen in the south-east among the stars of Aquarius. It is growing appreciably brighter as it approaches opposition.

A partial eclipse of the Sun on July 9 is visible only in Arctic regions.

Lyra. The bright star *Vega* is easy to find on a July night, for at midnight it is almost directly overhead. This is the brightest star of the constellation Lyra, which is supposed to represent the lyre which Orpheus played, and in which are to be found a variety of interesting objects. Just to the east of *Vega* is the star Epsilon Lyrae, which those with keen sight may recognize as a double star. In a telescope each of the two stars is seen to be double, the four almost identical stars forming a quadruple system (see page 209). To the south of this star and *Vega* lie four stars arranged in a small parallelogram, and this is all that the eye usually sees of this constellation. The two most southerly stars are Gamma (to the east) and (to the west) Beta Lyrae, and half-way between them lies the famous Ring Nebula (page 210). In an ordinary telescope this appears as an almost perfect luminous ring, a nebula, shining with the light of glowing gases. In a powerful instrument the dark interior of the ring is seen to be glowing faintly, and in the centre is a small star. The star is difficult to see, but easy to photograph – it it an intensely hot star, and its ultra-violet radiation makes the ring of gases glow with light. It is not really a ring, but a hollow shell, formed probably in the past by some great explosion, when

the star threw off part of its surface as a gas cloud. The Ring Nebula is typical of the so-called planetary nebulae, which are badly named, although they may look a little like a planet out of focus. Nearly four hundred of these objects are known, most of them in or near the Milky Way.

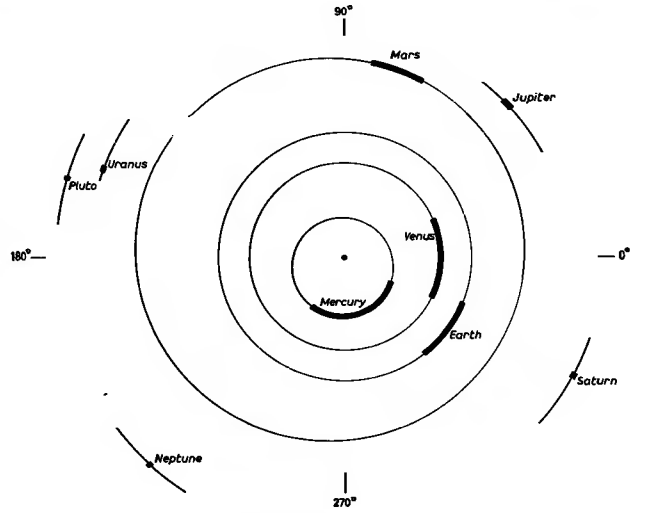
Another interesting object in Lyra is the star Beta Lyrae, a very remarkable variable star. The variations in its light were first reported in 1785 by John Goodricke, the remarkable deaf and dumb astronomer of York. He showed that the light of the star varied in a regular manner every 13 days, and although he did not attempt to give an explanation, it soon became clear that this was a case of an eclipsing binary star. There is actually a double variation of light, which sinks to 58 per cent of its value at the primary eclipse when the fainter star is in front, and to 91 per cent when the brighter star hides the other. The number of observations of this star must be a record, yet it still remains something of a mystery. Its spectrum is so complicated – there is no other bright star with a spectrum quite like it – that all of its problems have not yet been solved. We do know, however, that the system consists of two huge stars so close together that their tidal forces have drawn them out into an elliptical shape, and that they are almost touching. The brighter star, which we know most about, is perhaps 60 million miles across, and it is revolving in an orbit only 20 million miles in radius, so that the centre of the orbit must lie inside the star. The two stars are surrounded by a shell of luminous gas which is continuously expanding outwards, and the stars are revolving inside this gaseous mantle. As they do so, they shed part of their surfaces, the bright star giving off a dense stream of hot gases which flows round the other star, and this, in its turn, emits a stream of cooler gas. We rather lose track of the gases at this point, but they must contribute to the content of the great expanding envelope which surrounds the whole system. This is obviously a very exceptional system, but it is the exception that proves the rule, and provides a great deal of the interest in modern astronomy.

August

New Moon: August 7 *Full Moon:* August 23

Mercury is at greatest eastern elongation (27 degrees; morning star) on August 5, but it is then well south of the Sun, and will not reach a sufficient altitude to be seen in the dawn sky.

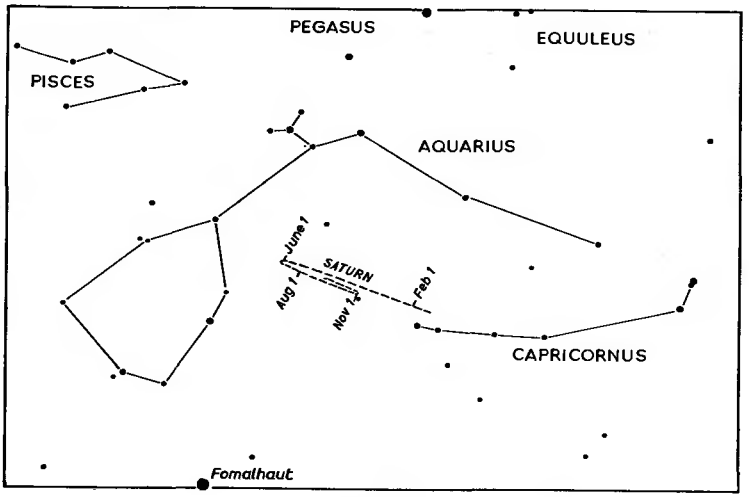
Venus is now at its best as a morning star, rising nearly 4 hours before the Sun, and reaching greatest western elongation (46 degrees) on August 29. The planet will again be seen near Mars at the end of the month (4 degrees south of Mars on August 28).



Planetary Orbits in August

Mars is a morning star in Gemini, and now rises well before the Sun. It is not very bright as yet (magnitude +1·7), but by the end of August it will form a striking configuration with the Twins, *Castor* and *Pollux*, and on August 28 Venus will pass about 4 degrees south of Mars. This will be the third successive conjunction of Mars and Venus within a year, the two previous occasions being on 1963 November 20 and 1964 July 18.

Jupiter now rises well before midnight, and will be seen on the borders of Aries and Taurus, to the west of the Pleiades. The planet is now somewhat brighter, reaching magnitude −2·1 at the end of August. The autumn months afford a suitable opportunity for watching the various phenomena of Jupiter's satellites; during the present apparition only the three inner satellites undergo the usual series of eclipses, transits and occultations.



Saturn

Saturn is at opposition on August 24, and is then visible all night. It should easily be recognized as the brightest object in the constellation Aquarius, its magnitude being +0·6. The distance at opposition is 816 million miles, and although this is less than at the 1963 opposition, the planet is not quite as bright because the rings are now closing; at opposition they are tilted to our line of sight at about 9 degrees. At a more favourable opposition, when the rings are fully open, the planet may be a whole magnitude brighter. The rings of Saturn, as well as its largest satellite Titan, may be seen in quite a small telescope (see note on page 64).

Meteor streams. It is just a century since it was shown that there

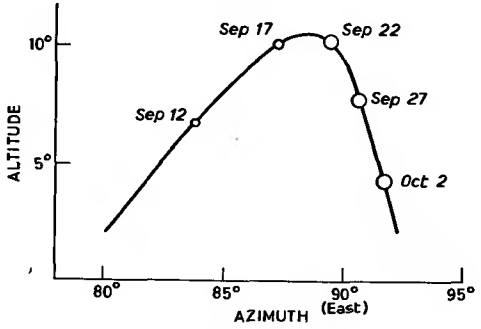
was a definite connexion between certain comets and some of the annual showers of shooting stars. One of the first orbits to be investigated in this way was that of the August meteors, the Perseids, which were found to travel round the Sun in the same path as Tuttle's comet of 1862. The assumption is made that meteors are caused by the debris of comets – the dust that they leave behind them as they travel round the Sun – but this trail of dust must come very close to the Earth's orbit, so that only a few comets can give rise to meteor showers in this way. The Perseids are always to be seen in a clear night in the first two weeks of August, rushing swiftly across any part of the sky, but always along straight lines which appear to radiate from a point high up in Perseus, on the border with Cassiopeia. The Perseids were once known as the 'Tears of St. Lawrence', because they were seen at their best on August 10, the Feast of St. Lawrence. But like all such paths in space, the orbit of the Perseids twists slowly round, so that the place where it cuts the Earth's orbit has moved forward, and the Earth reaches this point on August 12. If the dust were concentrated in one spot, there would be just one display of shooting stars on that night, but the Perseid stream is an ancient one – it has been recorded in the archives as far back as the year A.D. 830 – and so the dust has spread out into a broad belt round the orbit. As a result, Perseid meteors may be seen at any time between July 27 and August 17, although they still reach a maximum number on August 12.

The orbit of the Perseids is a large one, and the dust takes 33 years to go round the Sun. As a contrast, the orbit of the December Geminids is an eccentric ellipse, in which the dust takes only about 20 months to complete a revolution about the Sun. The Geminids rank with the Perseids in producing a good shower of meteors, and on the night of maximum, December 12, an observer may expect to see about one Geminid per minute, this figure referring to the whole sky, which, however, cannot all be watched at the same time. The Geminid meteors appear to radiate from a point in Gemini, near the star Castor; they have no long history, like the Perseids or Leonids, and are probably of more recent formation, although no known comet has an orbit so small.

September

New Moon: September 6 *Full Moon:* September 21
Equinox: September 23

Mercury is at inferior conjunction on September 2, but it moves rapidly to greatest western elongation (18 degrees; morning star) on September 18, when it will be well placed for observation. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon; this is about 30 minutes before sunrise at this time of year. The changes in brightness are roughly indicated by the sizes of the circles; it will be seen that Mercury is brightest after the date of western elongation.

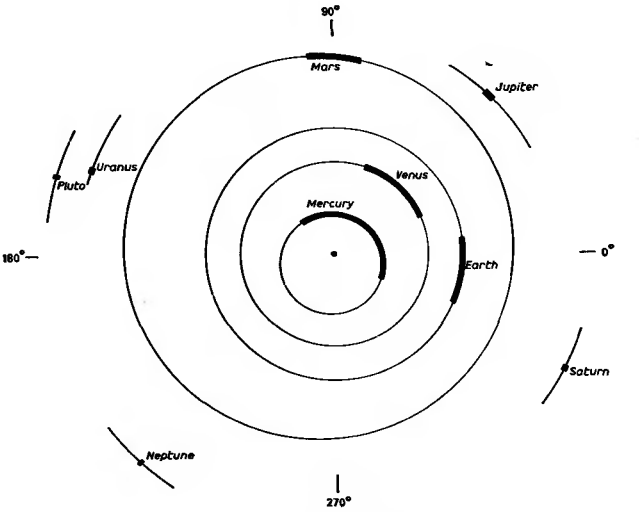


Mercury, September

Venus is a morning star, and although a little less bright (magnitude −3·9 to −3·7) it is still a fine object in the eastern sky at dawn. The planet remains well north of the Sun, and at the equinox, with the Sun on the equator, Venus still has a declination of 15 degrees north.

Mars is also a morning star in Gemini, and at the beginning of the month is only a few degrees to the north-west of Venus. Its direct motion takes it some degrees south of *Pollux* on September 5 (magnitudes Mars +1·6, *Castor* +1·6, *Pollux* +1·2) and it moves

into Cancer in the middle of May. It will be south of the star cluster *Praesepe* at the end of the month.



Planetary Orbits in September

Jupiter is a brilliant evening star (magnitude −2·2), rising in the late evening in Taurus. It is now moving slowly eastwards to the south and west of the Pleiades, but it does not reach this cluster, as it comes to a stationary point on September 14, and then begins its retrograde motion. Jupiter will be seen just north of the Moon (4 days past the Full) on the night of September 25.

Saturn is an evening star, and will be seen in the south in the late evening. It is still moving retrograde in Aquarius.

Vesta may reach magnitude 6 at the time of opposition on September 2. (See note on page 76).

The four great moons of Jupiter. The four largest satellites of Jupiter are always a fascinating study, and may be seen with quite a small telescope, appearing as four bright pin-points of light that move round the belted planet. Their orbits are almost edge-on to

us, so that they pass in front of Jupiter as they move from east to west, swing out into space, pause, and swing back again. This time they pass behind the planet, and may either be occulted by the planet or undergo eclipse in Jupiter's enormous shadow. The transit of a satellite across the face of Jupiter is always preceded or followed by a transit of the satellite's shadow, but these are not easy to see in a small instrument, since both satellite and shadow tend to merge into the background formed by the bright surface of Jupiter. Eclipses, however, are easily seen, and are always interesting.

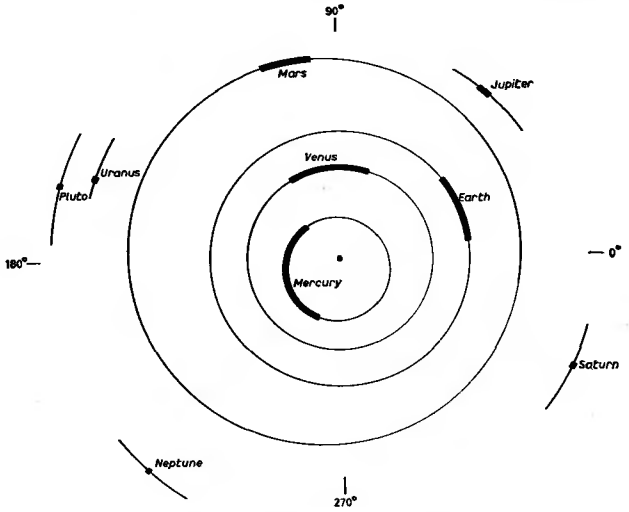
Jupiter has twelve moons, but the other eight are much too small and faint to be seen with ordinary telescopes. Even from the surface of Jupiter, the outer seven would be invisible without quite a large telescope. The four big satellites, which are about the same size as our own Moon, would not appear as bright as our Moon does to us, because the Sun is five times as far away. Its light would therefore be only about 4 per cent of the amount that we receive on Earth. Satellite I, which is about the same distance from Jupiter as the Moon is from the Earth, would appear to be about the same size as our Moon, but a good deal less bright; the other three would appear progressively smaller and fainter. All four moons would exhibit the usual phases, but satellites I, II and III would be seen in eclipse at every revolution. Only satellite IV is far enough away from Jupiter to escape the great shadow of the planet, on those occasions when it is tilted to its greatest extent towards or away from the Sun. This tilt is only about 3 degrees, but this is enough to allow satellite IV to pass above or below the shadow. Jupiter is tilted in this way at the present time and satellite IV does not undergo any of these phenomena. The fifth satellite, nearest to Jupiter, is very much smaller, but it is of interest because it travels round Jupiter at a distance of 112,500 miles (half the distance of the Moon from the Earth) in a period of 12 hours. This means that it is the fastest natural satellite in the solar system, moving at 1,000 miles a minute, or twenty-five times as fast as our Moon.

October

New Moon: October 5 *Full Moon:* October 21

Mercury is at superior conjunction on October 15 and will not be visible during the month.

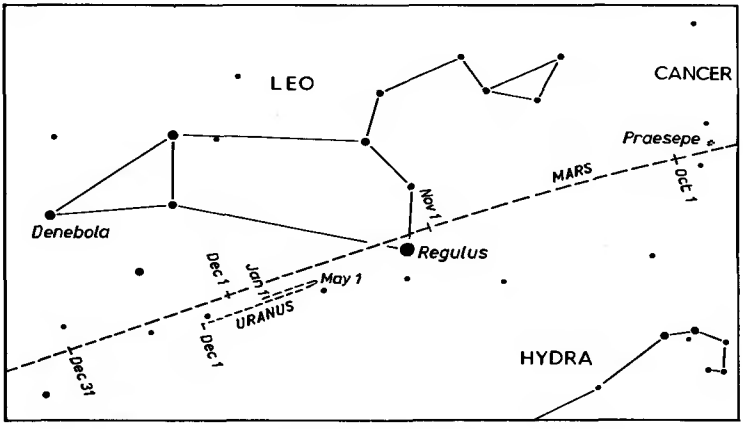
Venus still rises some hours before the Sun, and is a brilliant object in the east before dawn. Two interesting conjunctions of Venus take place during this month, and should be observable with binoculars. On October 5 the planet passes less than half a degree south of *Regulus*, and on October 17 it will be very close to the



Planetary Orbits in October

planet Uranus. The closest approach occurs at about midnight, but even at 4^h Venus will be less than a quarter of a degree north of Uranus, and with any sort of optical aid both planets should be visible in the same field of view.

Mars is a morning star, rising just after midnight. It moves from Cancer into Leo at the middle of October, and begins to brighten a little (magnitude +1·5 to +1·4) as its distance decreases. At the



Mars and Uranus

end of the month Mars will be found near *Regulus* (magnitude +1·3).

Jupiter now rises north of east in mid-evening. It is moving retrograde on the borders of Taurus and Aries, and its brightness continues to increase as it approaches opposition (magnitude −2·4). The planet will again be seen close to the Moon on the night of October 22.

Saturn is an evening star in the south in the early evening hours, and is visible for most of the night. It is now moving slowly among the stars of Aquarius, and is a little less bright (magnitude +0·8).

Saturn's satellite Titan. Although fainter than the four big satellites of Jupiter, Saturn's satellite Titan is quite a suitable object for a small telescope. Titan is the largest satellite in the solar system, and it appears to be fainter than those of Jupiter merely because it is about twice as far from us and from the Sun. It revolves about Saturn in a period of about 16 days, but under normal conditions it does not undergo the succession of transits and eclipses that make the four moons of Jupiter so fascinating to watch. Saturn is tilted at such an angle (28 degrees) that Titan appears to pass above or below the disk of the planet at each conjunction; it is only when the planet is seen at such an angle that the rings and the orbits of

the satellites appear almost edge-on that these phenomena can take place. This does not happen in 1964, but the rings are closing, and the eclipses and transits of Titan will be seen again in two or three years' time. Diagrams showing the position of Titan are given annually in the *Handbook* of the British Astronomical Association.

Aquarius. The constellation Aquarius, in which Saturn is to be seen at the present time, is one of the many star groups in this part of the sky that have something to do with water. There is the dolphin (Delphinus) and the fishes (Pisces and Piscis Austrinus), the whale (Cetus) and the sea-serpent (Hydra); and even the goat (Capricornus) is a sea-goat, half animal, half fish. There, too, is the River Eridanus, winding down to the southern skies, whose waters have their magical source in the jar which Aquarius is holding. The constellation is an old one, and the water which flows from the jar was once the source of a proverb, as well as of a river. Manilius, the Latin poet, in his astronomical poem, ends his description of Aquarius with the words '. . . and so the urn flows on', and this became a common figure of speech in referring to people who will keep on talking. In some old English books Aquarius is referred to as 'The Skinker', and this old Anglo-Saxon word may still be found in some modern dictionaries. It means a tapster, one who serves drink, and it comes as something of a shock to have such a word applied to a star group.

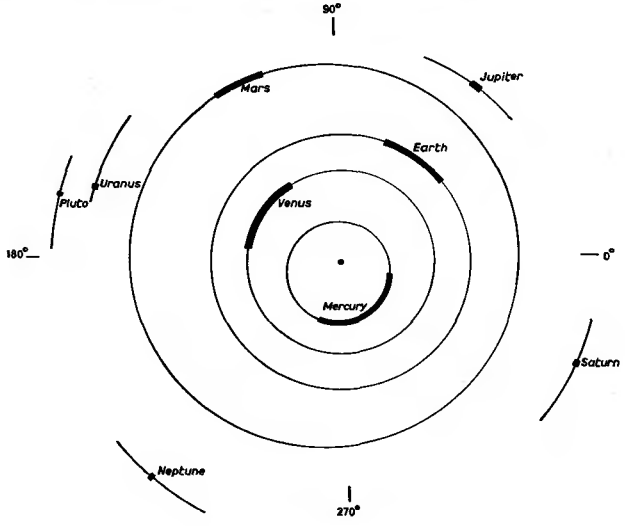
The International Astronomical Union. The International Astronomical Union, which co-ordinates the work of astronomers all over the world, is holding its twelfth General Assembly in Hamburg this year. These conferences are held every three years, and the last meeting in Berkeley, California, in 1961, brought together nearly 800 astronomers from thirty-eight different countries. Their discussions covered every branch of astronomy, both practical and theoretical, from the history of astronomy to the most modern theories and equipment, from meteors to magneto-hydrodynamics, from the solar system to the most distant galaxies. Hamburg has much to offer the assembled scientists, and the ample facilities of the University should ensure the success of this meeting.

November

New Moon: November 4 *Full Moon:* November 19

Mercury is at greatest eastern elongation on November 30 (21 degrees; evening star), but is then well south of the Sun, and will not reach a sufficient altitude to be visible in the twilight sky.

Venus is still a fine object in the east at dawn (magnitude −3·5). The planet crosses the equator into southern declinations on November 3, but it is still well north of the Sun.



Planetary Orbits in November

Mars rises at midnight at the beginning of the month, and is in the south at dawn. It is now moving more slowly through Leo, and passes rather more than a degree north of *Regulus* on November 4 (magnitudes Mars +1·4, *Regulus* +1·3). Mars is now growing noticeably brighter, and reaches magnitude +1·0 at the end of November.

Jupiter is now at its brightest as an evening star (magnitude −2·4),

and reaches opposition on November 13. The planet moves westwards into Aries at the beginning of the month, and will remain in this constellation for the rest of the year. This opposition is a very favourable one, Jupiter being now 17 degrees north of the equator and high in the sky at midnight. The distance at opposition is almost exactly four astronomical units, or 372 million miles.

Saturn is at a stationary point on November 2, and then begins its direct motion eastwards once more. It sets at midnight at the beginning of the month in the south-west.

The Leonids. In November, particularly about the 16th of the month, it is possible to see a few fast-moving shooting stars, which appear to come from a point above the Sickle of Leo. These are called the Leonids, and although the display is likely to be rather disappointing, this shower is of considerable interest. The Leonids are among the fastest moving of all meteors, because in November the Earth is moving towards the star *Regulus*, and since the Leonids are coming from that direction, they meet the Earth almost head-on. Travelling through our atmosphere at more than 40 miles a second, they burn themselves out to form swift straight streaks of light which may be seen in any part of the sky, but which all appear to radiate, like the spokes of a wheel, from this point in Leo. This is an effect of perspective, just as railway lines appear to vanish together at a point in the distance. Knowing the position of the Earth at the time, and the point in the sky from which the meteors have come, it is possible to calculate the orbit in which the meteoric dust is travelling. In the case of the Leonids, the orbit is the same as that of Tempel's Comet of 1866.

At one time the Leonids gave magnificent displays of shooting stars, and historical records of these have been found dating back to A.D. 902. In 1833 and again in 1866 the meteors of the Leonid shower fell like snowflakes, the whole sky being crossed with their streaks of light at the rate of hundreds a minute. Nowadays the shower is unlikely to produce more than a few meteors in an hour's watch, but this is still called a 'shower', because the number of meteors is above the average. In any case, the Leonids can be

recognized by their swift streaks, and by tracing these backwards to the radiant above the Sickle of Leo.

Orion. Prominent among the constellations in the south-east on a November night

Begirt with many a blazing star
Stands the great giant Algebar,
Orion, hunter of the beast!

This great star group is tilted to the left as it comes over the horizon. Orion seems to be very careful about the manner of his rising; he may be a giant, but there is one thing he fears – the Scorpion. It was a scorpion that put an end to his existence when he was down here on Earth, and even now, up there among the stars, Orion will never appear if the Scorpion is at all visible, and in the spring he disappears in the south-west before Scorpio rises in the east.

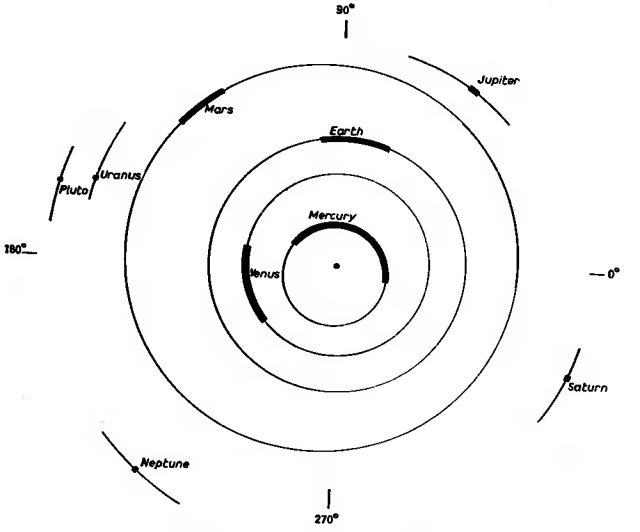
Orion is always pictured as a giant who is warding off the attack of Taurus, the Bull. In the seventeenth and eighteenth centuries many star atlases were published which illustrated these constellation figures with a certain amount of artistic skill. Bayer, in 1603, drew Orion with his back towards us, holding a club in his left hand, and with his head turned to the left – apparently ignoring Taurus completely. The atlas of Flamsteed, the first Astronomer Royal, produced some years later, has Orion looking at the Bull, and with his body turned towards us, his club in his right hand. These two atlases seem to have influenced all the others, and there are two rival lines of thought. You may have a left-handed Orion, looking the wrong way, with his sword strapped round the middle of his back; or, if you prefer, you can have a right-handed giant who is imminent danger of tripping over his sword or over the hare (Lepus) that sits at his feet.

December

New Moon: December 4 *Full Moon:* December 19
Solstice: December 21

Mercury is at inferior conjunction on December 18, and will not be visible during the month.

Venus is still a brilliant spectacle in the morning sky before sunrise, but it is now moving in to superior conjunction, and is much lower in the sky in the south-east, and visible for a shorter period before dawn.



Planetary Orbits in December

Mars now rises in the east before midnight, and will be seen below the figure of Leo. There is a rapid change in the brightness of the planet as its distance decreases (magnitude +1·0 to +0·3), and by the end of the year, when it is about 102 million miles from the Earth, it will be more than six times as bright as it was in August. Mars passes into Virgo at the end of December, and will be at opposition on 1965 March 9 on the borders of Leo and Virgo.

Jupiter is a bright evening star, to be seen in the south in mid-evening. It is still moving retrograde, but reaches a stationary point in early January. Jupiter will be at opposition in 1965 December, when it will be seen on the borders of Taurus and Gemini.
Saturn is an evening star, setting before midnight in the south-west in Aquarius. The next opposition of Saturn occurs in 1965 September.
A partial eclipse of the Sun on December 4 will be visible only in the north Pacific Ocean and bordering countries.
A total eclipse of the Moon on December 19 will be visible in the British Isles, beginning about an hour before midnight. Totality lasts from $2^h\ 07^m$ to $3^h\ 07^m$, and the eclipse ends at $4^h\ 15^m$ (see page 72).
The length of the day. In astronomical circles it is generally unwise to refer to seasonal effects, such as the spring equinox or the winter solstice, without carefully defining these terms. There are many astronomers in the southern hemisphere, where the seasons are completely reversed, and to refer to the summer solstice when they are in the depths of winter is sometimes a little tactless. To the ordinary reader, the word solstice conveys very little, and perhaps this is why the word is avoided by the makers of diaries. Our pocket diaries may give the dates of the equinoxes, but the solstices are not mentioned; instead, the entry simply reads 'June 23, Longest Day' or 'December 21, Shortest Day'. This is, of course, equally objectionable to those who live south of the equator, and presumably these diaries are intended only for northern latitudes. The statement is then (at least in theory) perfectly correct, for it is necessarily true that the shortest day must occur when the Sun is at its lowest in the sky, that is, when it reaches its greatest southern declination at the solstice. In actual fact, however, the Sun is changing its declination so slowly at this time that the days are of equal length for about a week. What is much more noticeable is that at the end of December the evenings are already becoming lighter, while the Sun continues to rise later each morning. We may illustrate the fact with a table of times of sunrise and sunset for the present year (in latitude 52 degrees north), although the figures

will not be more than a minute or so in error in any other year.

	Mean time			*Apparent time*	
	Sunrise	*Appt. noon*	*Sunset*	*Sunrise*	*Sunset*
	h m	h m	h m	h m	h m
Dec. 1	7 45	11 49	15 51	7 56	16 02
6	7 52	11 51	15 50	8 01	15 59
11	7 58	11 53	15 49	8 05	15 56
16	8 03	11 55	15 49	8 08	15 54
21	8 06	11 57	15 50	8 09	15 53
26	8 07	12 00	15 53	8 07	15 53
31	8 08	12 02	15 58	8 06	15 56
Jan. 5	8 08	12 04	16 04	8 04	16 00
10	8 05	12 07	16 10	7 58	16 03
15	8 01	12 09	16 18	7 52	16 09

The table shows that the time of sunrise continues to be later each day until the beginning of January, whereas the time of sunset has already reached its earliest in mid-December. Thus the familiar comment that 'the evenings are drawing out' is a simple statement of fact. The reason for this state of affairs is the rapid change in the equation of time at this season (see the note on 'The Sundial' on page 40). Sunrise and sunset are phenomena of the apparent Sun, but our clocks keep mean time, not apparent time, and we are accustomed to judge the time of noon by the clock, and not by the Sun. The third column in the table gives the mean time of apparent noon, and here we see the effect of the changing equation of time. The Sun is in the south, not at 12 o'clock, but at times which are growing later by about half a minute each day. The length of the morning (from sunrise to apparent noon) is equal to the length of the afternoon (from apparent noon to sunset), but the midpoint of the day, when the Sun is due south, is swinging over from before-noon to after-noon. In the last two columns of the table the equation of time has been added to the mean times of sunrise and sunset, so as to give the apparent times of these phenomena. It will now be seen that the shortest day is indeed on December 21, the day of the solstice.

Eclipses, 1964

In 1964 there will be six eclipses, four of the Sun (all of which are partial eclipses), and two total eclipses of the Moon. Of these, only the two lunar eclipses are visible in the British Isles.

1. *A partial eclipse of the Sun* on January 14, visible only in Antarctica, Tasmania and the southern point of South America. This eclipse belongs to a series which is moving north and increasing in magnitude.
2. *A partial eclipse of the Sun* on June 10, visible only in Australia and New Zealand. This eclipse occurs at the end of a series which is moving south; the last total eclipse in the series was in 1910.
3. *A total eclipse of the Moon* on the night of June 24, visible in the British Isles. The shadow of the Earth will first be seen at the extreme eastern limb of the Moon at $23^h\ 09^m$, and it will appear to move to the right across the face of the Moon until total eclipse occurs shortly after midnight – June 25 at $00^h\ 16^m$. The Moon will then be due south, and the totality lasts for 100 minutes, ending at $1^h\ 57^m$. The shadow continues to move westwards, finally passing off the Moon at the west limb at $3^h\ 03^m$.
4. *A partial eclipse of the Sun* on July 9 is the third in a new series of eclipses which first appeared in 1928. The series is moving south, and this eclipse is visible only in Arctic regions.
5. *A partial eclipse of the Sun* on December 4 will be visible in eastern Asia, the north Pacific Ocean and Alaska. It occurs at the end of a series which is moving north and decreasing in magnitude.
6. *A total eclipse of the Moon* on December 19 will also be visible in the British Isles. The umbra of the Earth's shadow makes its first contact with the eastern limb of the Moon at $0^h\ 59^m$, and will move to the right across the Moon's face. Totality commences at $2^h\ 07^m$ and lasts for an hour, ending at $3^h\ 07^m$. The shadow passes off the west limb at $4^h\ 15^m$.

Occultations

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at the rate of about 20 degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about $6\frac{1}{2}$ degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first-magnitude stars that can be occulted by the Moon; these are *Regulus*, *Aldebaran*, *Spica* and *Antares*. In 1964, however, the Moon's path is in such a position that it passes north of all four stars, and they cannot therefore be occulted.

The planets Mercury, Venus and Mars are all occulted by the Moon in 1964, but these phenomena will not be visible in the British Isles.

Details of occultations of the planets, and of all stars down to magnitude 7·5, as well as possible occultations of stars by planets, are published in the annual *Handbook* of the British Astronomical Association.

Comets in 1964

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention. Unfortunately they are all faint objects, and are recovered and followed by photographic methods, using large

telescopes. Most of these short-period comets travel in orbits which carry them out to the orbit of Jupiter, and it is this planet which is responsible for the severe perturbations which many of these comets undergo. In 1964 the following short-period comets are expected to return to perihelion:

Comet Encke, which has the shortest period of any known comet (3·3 years), is named after the famous mathematician who first computed its orbit. Encke was able to show that the comet of 1818, discovered by Pons, was the same as Méchain's comet of 1786, with Caroline Herschel's of 1795, and with Pons's comet of 1805, and he predicted another return in 1822. This was the second instance of a predicted return, that of Halley's comet in 1759 being the first. Encke's comet has been seen at forty-six returns to the Sun and is expected in 1964 May.

Comet Pons-Winnecke has been seen at fifteen previous perihelion passages since its discovery in 1819. It has a period of about 6·1 years and is greatly perturbed by Jupiter at alternate revolutions. It was not seen in 1957, but is expected at perihelion in 1964 March. As a result of the perturbations the orbit is growing larger and less eccentric, while the inclination is increasing.

Comet Kopff, last seen in 1958, was discovered in 1906 and has made eight appearances. It has a period of 6·3 years and is due to return in 1964 May.

Comet Daniel was discovered in 1909, but has been seen since then only at the 1937, 1943 and 1950 returns. It has a period of 6·7 years and is due at perihelion in 1964 April.

Comet Arend-Rigaux was discovered by two Belgian astronomers in 1950, and was also seen at the 1957 return; it is predicted to return to perihelion in 1964 June.

Comet Shajn-Schaldach is also due in 1964 June. It was discovered independently by Mrs. P. Shajn at the Simeis Observatory, Crimea, and by Robert D. Schaldach at the Lowell Observatory, Flagstaff, Arizona, in 1949, but it was missed in 1958. If the computed orbit is correct, this comet has a period of 7·3 years, and its next perihelion passage is in 1964 June.

Comet Honda-Mrkos-Pajdusakova was discovered in 1948, and

was seen in 1954 but not in 1958. It has a short period of 5·2 years.

Comet Wolf-Harrington is an example of a comet that was thought to be a new one, but was found to have been seen previously. Harrington discovered this comet in 1951 on the sky survey plates taken at Mount Palomar Observatory, but it appears to be identical with comet Wolf (1) seen only at one previous return in 1924. The comet was observed in 1958.

Comets Schwassmann-Wachmann (1) and *Oterma* are visible every year because they travel round the Sun in orbits which are much more nearly circular than those of most other comets. Comet Schwassmann-Wachmann has an orbit with a period of 16 years which lies entirely between the orbits of Jupiter and Saturn. It undergoes remarkable changes of brightness, which seem to have some connexion with solar activity. Comet Oterma has a smaller orbit, lying between those of Mars and Jupiter, and resembling the orbits of certain minor planets. The period at present is nearly 8 years, but Miss L. Oterma has shown that the comet will make a close approach to Jupiter in 1962–64, and this will cause the orbit to become much larger and more eccentric, with a period of 19 years. As a result the comet will only be visible in large telescopes in future years, because its perihelion distance will have increased from 3·4 to 5·3 astronomical units.

Meteors

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors fallen so fast as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but

even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1964 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Note*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\ 28^m$	$+50°$	
April 20–22	Lyrids	April 22	$18^h\ 04^m$	$+33°$	
July 27–Aug. 17	Perseids	Aug. 12	$3^h\ 04^m$	$+58°$	
Oct. 15–25	Orionids	Oct. 20–21	$6^h\ 24^m$	$+15°$	M
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\ 36^m$	$+14°$	
Nov. 15–17	Leonids	Nov. 16	$10^h\ 08^m$	$+22°$	M
Dec. 9–14	Geminids	Dec. 13	$7^h\ 28^m$	$+32°$	
Dec. 20–22	Ursids	Dec. 22	$14^h\ 28^m$	$+76°$	M

M = moonlight interferes

Minor Planets in 1964

Of the 1,600 minor planets which are listed in the catalogues, only the 'big four', Ceres, Pallas, Juno and Vesta, can reach any considerable brightness, and only the last of these, Vesta, can occasionally be seen with the naked eye. This may happen in 1964 at the time of opposition on September 2, when Vesta is in Aquarius, some degrees south-east of Saturn, and about 12 degrees north of the first-magnitude star *Fomalhaut*.

The planets Pallas and Juno both come to opposition on May 18, but are widely separated in the sky, Pallas being well north in Hercules, while Juno is on the borders of Libra and Serpens. Ceres is in opposition on June 21 in Sagittarius, and at this time may reach the seventh magnitude.

Some Events of 1965

ECLIPSES

In 1965 there will be three eclipses, two of the Sun and one of the Moon; in addition there will be a penumbral lunar eclipse.

May 30 – a total eclipse of the Sun, visible in the south Pacific.

June 14 – a partial eclipse of the Moon, visible in the British Isles.

Nov. 23 – an annular eclipse of the Sun, visible in India, Borneo and New Guinea.

Dec. 8 – a penumbral eclipse of the Moon.

THE PLANETS

Mercury may best be seen as an evening star at eastern elongation on March 21, and as a morning star at western elongation on September 2.

Venus will not be a very conspicuous object until the end of the year; it comes to greatest elongation as an evening star on November 15, and is at greatest brilliancy on December 21.

Mars will be in opposition on March 9, reaching magnitude −1·0 among the stars of Leo. Conditions will be much the same as in 1963, with Mars at a distance of 62 million miles, but farther south in the sky.

Jupiter is in conjunction on May 30, and at opposition on December 18 on the borders of Taurus and Gemini.

Saturn will be in conjunction on February 26 and at opposition on September 6 in Aquarius.

Uranus will be at opposition on March 3 and *Pluto* on March 5, both planets being in Leo; *Neptune* is at opposition on May 9 in Libra.

The Distance of the Sun

J. G. PORTER

The advent of space research, and particularly the launching of interplanetary probes, has created a demand for a more precise knowledge of the actual distances between the planets. These distances are measured by the astronomer in terms of the *astronomical unit*, which may be regarded as the mean distance from the Earth to the Sun, but the actual length of this unit in miles or kilometres is of little interest to him; he is more concerned with angles, or proportions, than with actual distances. It is only in those cases where the size of the Earth enters into his calculations that any use is made of the distances. For example, in dealing with eclipses, the lengths of the shadows of the Earth and Moon are required, and the Sun's distance must therefore be included in the calculations. Yet even here it is used in the form of an angle – in this case it is the *solar parallax*, which is the angle subtended by the equatorial radius of the Earth at the distance of the Sun. This is a very small quantity, amounting to only a few seconds of arc, and as it plays only a minor part in these calculations, it is sufficient to have its value known to three-figure accuracy. Thus in the *Astronomical Ephemeris*, the value of the solar parallax is taken as $8''{\cdot}80$, and although it is known that this is not precisely correct, it suffices for this type of work.

In most astronomical studies the actual scale of the solar system does not matter – it is the proportions that are important. Now, the proportions of the mean distances of the planets from the Sun are known with great accuracy, because the time of revolution of a planet about the Sun is related to its distance from that body through Kepler's third law (this states that the square of the period

in years is equal to the cube of the distance in astronomical units). In this way we can prepare a very accurate map of the whole solar system, but the precise scale of that map is not known with sufficient precision to please the space scientists.

Additional errors arise from the fact that the positions of the planet as given in the *Ephemeris* are based on theories which are already more than sixty years old, and although recent improvements have been made by Duncombe (for Venus) and Clemence (for Mars) these have not yet been generally adopted. Thus we have the situation that the distances of the planets, given in the *Ephemeris* to seven places of decimals (in astronomical units), are not really known to such accuracy; in fact, it is doubtful if we know the positions of any of them to better than five decimals, or, say, the nearest thousand miles. Clearly, for space research something better is needed, but the determination of these distances by astronomical methods is no easy matter.

The first attempt was made by Aristarchus more than 2,000 years ago, by measuring the angles between the Sun and Moon at First Quarter. This is very difficult to do successfully, and his result was that the Sun was only twenty times as far away as the Moon. Ptolemy used a similar method with eclipses, and found a value for the Sun's distance of 1,200 times the radius of the Earth; this is equivalent to about 4½ million miles, but such was the authority of Ptolemy that this value was used without question for the next 1,500 years. In the sixteenth century Kepler and his contemporaries knew that this value was too small. Huygens, for example, guessed that 12,000 Earth radii was a better answer, but it was Cassini who first obtained a reasonable result. He used observations of Mars, sending one of his assistants to the new colony of Cayenne, while he himself observed in Paris. The two stations would see Mars in slightly different directions, and the difference between them could be used to calculate the distance of Mars. Since the proportions of the planetary orbits are known very accurately, a measure of the distance between any two of them gives at once the scale of the whole system, and this method, first used by Cassini, is the basis of all subsequent astronomical measurements. Cassini's result for

the Sun's distance was 86 million miles, which is about 7 per cent too small.

In the next century, acting on a suggestion made by Halley, attempts were made to measure the distance of the planet Venus on the rare occasions when it passes across the face of the Sun. Although great preparations were made, the results were disappointing, because Venus has a dense atmosphere, and as it transits the face of the Sun, it has no sharp outline, while at the time of contact with the edge of the Sun, the planet seems to be surrounded with a bright aura, and it is impossible to time the exact moment of contact. However, the results were worked up, not only in 1761, but also again at the transit of Venus in 1769, and a value of the Sun's distance of 95,370,000 miles was obtained; this value was used for more than thirty years in the middle of the following century. Many astronomers were far from happy about this result. For example, Hansen, dealing with the motion of the Moon, pointed out that it was quite impossible to account for the position of the Moon near First and Last Quarter if this value were used, and he suggested that it should be about 3 per cent smaller.

Towards the end of the nineteenth century the distance was measured by Cassini's method, but some of the minor planets were used instead of the planet Mars. These are so small that they look like stars, so that their positions are more easily measured; also they are not coloured, and they come closer to the Earth than any of the major planets. The results from these measurements, using the planets Victoria, Iris and Sappho, were in good accordance, and gave a value of 8″·80 for the solar parallax, corresponding to a distance of 92,890,000 miles for the Sun's distance; this value has been used in the *Ephemeris* since 1900. At the opposition of the small planet Eros in 1931, when it came within 16 million miles of the earth, a great campaign was organized to establish a better value for the astronomical unit. The improvements in instruments, the use of photography, and the large number of observations, all combined to make this a more reliable value. In all, forty-four observatories from all parts of the world took part, and the resulting calculations, which took ten years to complete, gave a

value of 8″·790 for the solar parallax, corresponding to a distance of 93,005,000 miles.

In recent years a re-discussion of the Eros campaign has been made by Rabe, of Cincinnati Observatory, who used all the additional knowledge acquired in the intervening twenty years to deduce an improved value of 8″·7984 (92,911,000 miles), and this may be accepted as the best value that astronomical methods can obtain. Even here, the last figure may be several units in error, so that this does not give a value for the Sun's distance to an accuracy better than about one part in 20,000. None of these astronomical methods is a direct measurement, but is actually a deduction from the laws of celestial mechanics. It is only in recent years that direct measurements of the distance of a planet have been made by radar, and all of these have been applied to Venus at the time of inferior conjunction. The latest and most detailed of these experiments was carried out at the April 1961 conjunction of Venus by the staff of the Jet Propulsion Laboratory of the California Institute of Technology, Pasadena.

The transmitting and receiving antennas have similar parabolic reflectors 85 feet in diameter, and these are placed about seven miles apart at Goldstone, near Barstow, California. The transmitter, with a power of 10 kilowatts, used a frequency of 2,388 megacycles (wave-length 12·5 centimetres), which was controlled to better than one part in 10^{10} by a crystal oscillator locked to a cæsium resonator. Two entirely different techniques were employed, in one of which the actual distance of Venus was measured by the time taken for the propagation of the radio signal to and from the planet; the other method used the Doppler shift in wave-length due to the relative velocities of the Earth and Venus. Since measurements of the Doppler effect give a value for the velocity of the planet towards or away from the Earth, they are most effective before or after inferior conjunction, and the experiments were continued from March 10 to May 10. At the conjunction itself, when the planet is moving on a course almost parallel with that of the Earth, the Doppler method is less valuable, and it is here that the range method is used. Even at its closest (about 26 million

miles) the time taken for the radio pulses to reach Venus and be reflected back to the receiver is nearly five minutes, and the signals were therefore coded in such a way that they could be identified. Five variations of the two methods were used in conjunction with the latest improved values for the positions and velocities of Venus and the Earth, derived from Duncombe's theory.

The five sets of results were remarkably consistent, and gave a final mean value of 8″·7940976 for the solar parallax, corresponding to a distance from the Earth to the Sun of 92,956,530 miles, with an estimated probable error of about 150 miles. The results are strongly confirmed by independent measurements made at the same conjunction of Venus by the Millstone Radar Observatory of the Lincoln Laboratory, Massachusetts Institute of Technology. Using a very different wave-length of 68 centimetres, they obtained a value of 149,597,700 kilometres, or 92,955,820 miles, in remarkable agreement with the J.P.L. values. The consistency of these results is so good that astronomers interested in the subject have been greatly impressed. The discrepancy between Rabe's results and those of the radar measurements has yet to be explained, and it will certainly be necessary to repeat the measurements many times, using, if possible, oppositions of Mars as well as future conjunctions of Venus. If successive results under differing conditions continue to give a similar value for the astronomical unit, then this will undoubtedly have to be accepted as the standard figure.

With Mariner 2 to Venus

H. G. MILES

On 1962 December 14 another goal in the exploration of space was reached when the first successful planetary probe, Mariner 2, flew to within 21,600 miles of the planet Venus. It was hoped that the probe would clear up some of the mysteries which surround the planet, but unfortunately it seems to have created many more questions. Many astronomers thought that Venus was not too different from the Earth. Even if Mariner's findings are not absolutely correct, it has shown that the planet bears very little resemblance to its 'twin' and that it is not a very hospitable place for an interplanetary traveller!

The Mariner project was developed for the National Aeronautics and Space Administration by the Jet Propulsion Laboratory of the Californian Institute of Technology. Within nine months from concept, two 'Mariners' had been constructed, tested and delivered to Cape Canaveral for launching, a feat that could not have been achieved without the dedication of all the scientists and technicians associated with the project. The first launch ended in failure when a fault in the ground support equipment forced the range safety officer to destroy the rocket just after launching. Success, however, came on August 27, when the second probe was launched. Apart from a few minor incidents, everything went according to plan. Information was sent back continually during the three months' journey to the planet, and even after it had passed Venus it still continued to send back information for another three weeks.

The Experiments

Mariner weighed 447 lb, but the scientific experiments accounted

for only 41 lb. Excluding the solar panels and the high gain aerial, it measured 5½ feet across and nearly 10 feet high. In the cruise position, with the solar panels extended, it was 16½ feet across. The hexagonal base housed the batteries, computers, the rocket motor for the mid-course correction and the radio equipment. The omnidirectional aerial was fixed at the top of the superstructure, whereas the highly directional aerial was hinged mounted to the base of the hexagon. Mounted at various points on the tubular superstructure were the instruments required for the scientific experiments.

The probe contained six experiments, two of which were designed to operate only when the spacecraft flew by the planet. One of these, the microwave experiment, was designed to give information on the atmosphere of Venus and also on the surface temperature of the planet. This was done by recording the intensity of the radiation at 13·5- and 19-millimetre wavelengths. These two wavelengths were chosen because the former is located in the water vapour absorption band, whereas the latter is unaffected by the presence of water vapour. The 19-millimetre radiation in addition to measuring the surface temperature of the planet, could also test the two theories regarding the atmosphere of Venus by detecting the presence of either 'limb darkening' or 'limb brightening'. The latter would confirm the presence of a dense ionosphere, whereas the former would show that the source of the radiation was the surface of the planet.

It was planned to turn on the experiment 10 hours before the encounter with the planet. The radiometer, which was nothing more than a 20-inch radio telescope, would scan up and down over an angle of 120 degrees at a rate of 1 degree per second. As soon as Venus had been located, the scan rate would drop to 1/10 degree per second. In addition, a special command system was built in so that as soon as the edge of the planet was reached the direction of the scan was reversed. Once located, the planet would be under continual observation. The lateral movement across the surface of the planet was achieved by the motion of Mariner as it flew by the planet.

The complementary experiment, using an infra-red radiometer, attached to the side of the microwave aerial, involved two wavelengths in the 8·5 and 10·4 micron region. The latter is absorbed by carbon dioxide, whilst the former is unaffected by the presence of this gas. Neither of these will, however, pass through cloud. A difference in the signal strength would give information regarding the carbon dioxide content in the atmosphere and in addition a varying signal strength from different parts of the planet would indicate the presence of breaks in the cloud layer.

The magnetometer experiment was designed to measure the strength and direction of the interplanetary magnetic field and also (if it existed) the magnetic field associated with Venus. The apparatus was mounted just below the onmidirectional aerial so as to be as far away as possible from any possible interference from other equipment on board the spacecraft.

The concentration and energy of interplanetary dust was determined using a cosmic dust detector. This consisted of a sounding board 10 inches by 5 inches. The number of dust particles striking the plate was recorded via a microphone mounted in the centre of the plate. There were two counters, one for high-momentum and the other for low-momentum particles.

The two other experiments involved the detection of high- and low-energy particles which are known to exist in large quantities in interplanetary space. The high-energy radiation experiment consisted of an ionization chamber and three Geiger-Müller counters. A knowledge of the concentration of these cosmic rays in regions well away from the Earth, and a knowledge of the way this concentration varied with solar activity, is vital for the understanding of the rather complicated changes in the character of the radiation reaching the Earth's surface. The solar plasma detector was designed to give information about the charged particles that are continuously being emitted by the Sun, the so-called solar wind. It consisted of a curved tunnel containing two plates, one negatively and the other positively charged. A charged solar particle is attracted by one plate but repelled by the other, and so it will

follow a curved path down the curved tunnel. Only those particles having the right speed will reach the end of the tunnel and enter a charged collecting cup. By varying the voltage on the plates, it was possible to collect details of the numbers of particles over a large energy range.

The Journey to Venus

The placing of Mariner on the course which took it to Venus consisted of three distinct operations. The Atlas booster rose vertically from Cape Canaveral and pitched over in the direction of South Africa. The Agena second stage fired for the first time and put the Agena-Mariner combination into a parking orbit with a speed of 18,000 mph at a height of 115 miles above the Earth's surface. Just before reaching the African coast, the Agena fired for the second time and boosted the speed to 25,503 mph, that is, about 850 mph above the escape velocity for that altitude. The probe therefore moved away from the Earth in a hyperbolic orbit. At the same time as it moved away from the Earth, it was slowed down by the Earth's gravitational pull, and by the time it had reached a distance of about 600,000 miles, the velocity had fallen to 6,874 mph. At this point it can be assumed that the probe had escaped from the Earth. The second-stage firing was timed so that the probe moved away in the opposite direction to that of the Earth's motion round the Sun. Mariner was therefore travelling round the Sun 6,784 mph slower than the Earth (approx. 66,000 mph) and could not therefore maintain a circular orbit against the Sun's gravitational pull. It consequently fell inwards towards the orbit of Venus. As it moved inwards it speeded up and by the time it passed between the Sun and Venus, it was travelling at 91,000 mph against Venus's orbital speed of 78,000 mph. Its path in the vicinity of Venus was designed so that the planet would not block the probe's view of the Earth.

Two minutes after reaching the peak velocity of 25,503 mph, the Agena rocket separated from the probe, rotated through an angle of 140 degrees and fired again, thus performing a retro-manoeuvre to put it on an entirely different orbit. This was done to

prevent the rocket from hitting Venus and also to prevent the spacecraft's optical system from confusing the Agena with the Earth or the Sun. Separation caused the spacecraft to tumble, but this was cancelled, using a gas stabilization system. Contact with the Earth was achieved via the omnidirectional aerial, and all communications with the probe were handled by the command subsystem. This decoded the incoming signals and sent them to the designated subsystem. It also coded the data obtained from the probe's instruments ready for transmission back to the Earth. The issuing of the commands to the spacecraft were handled by a digital Central Computer and Sequencer (CC and S). The CC and S was responsible for the launch sequences, the mid-course correction and the Venus encounter sequence.

The first command issued by the CC and S took place 49 minutes after launch when the solar panels were opened out and the radiometer unlocked. At launch +60, the CC and S instructed the probe to find the Sun. Sun sensors, linked to valves controlling gas jets, moved the probe until the solar panels were pointing directly at the Sun. To conserve gas, a tolerance of $\frac{1}{2}$ degree was allowed. After 7 days, the CC and S issued commands for the highly directional aerial to find the Earth. This was done by rotating the probe about its longitudinal axis until the aerial pointed directly at the Earth. If the Earth sensors had mistaken the Moon for the Earth, an overriding command would have been sent from the Earth to reject this and continue searching. As soon as the Earth had been acquired, all transmissions via the omnidirectional aerial were stopped.

It was soon apparent that the path taken by the probe was not exactly that required to give a fly-by of 10,000 miles. In fact, it would have missed Venus by well over a quarter of a million miles. Instructions were sent from the Deep Space Instrumentation Facility at Goldstone, California, giving the direction and amount of roll and pitch required and also the amount of velocity increment needed. These were stored in the CC and S until Goldstone transmitted the 'go' signal. This order was given on September 4. The following sequences of events illustrate the complexity of the

manoeuvre. Thirty minutes before the calculated time the stabilizing gyros were switched on. The Earth sensors were then switched off and the aerial moved out of the way of the motor exhaust. After the roll and pitch manoeuvres had been carried out, the probe was given 2 minutes to settle down. The mid-course motor was then turned on. Because the attitude control gas jets were not sufficiently powerful to maintain stability, this was achieved by using movable jet vanes extending into the motor exhaust. The motor was so precise that it could burn for as little as 50 milliseconds and could increase the velocity by as little as 0·7 feet/second or as much as 187 feet/second. Mariner then went through the Sun and Earth acquisition sequences for the second time.

The result of this manoeuvre corrected the path to nearly the required value. The smallness of the error is illustrated by the fact that the probe flew by Venus at a distance of 21,594 miles, which is only a little greater than the planned figure.

The 109-day journey to Venus brought one or two anxious moments. In the early stages the Earth sensors did not appear to be behaving normally, but this problem cleared itself when the sensitivity suddenly rose to the predicted level. On November 15 a short circuit developed in one of the solar panels, reducing the amount of power available. The scientific instruments were switched off to conserve power, but the short circuit healed itself and full power was restored. A week later the trouble returned, but fortunately there was still sufficient power available.

Although increasing temperatures brought one or two anxious moments, the biggest headache occurred just prior to the planet encounter. The CC and S had been programmed to activate the scanners 10 hours before the nearest approach. At the appointed time nothing happened! The scientists waited several hours to see if the switch-on would occur after the computer had gone through another cycle of operations, but still nothing happened. Fortunately, provision had been made for the probe to obey signals from the Earth, and when this signal was given Mariner responded and the radiometers started scanning. Contact with the planet lasted for 42 minutes and then Mariner went back to its 'cruise'

mode and sent back information on conditions in space for another 20 days.

The Results

The first news conference giving details of the information gained by Mariner as it flew by Venus was held on 1963 February 26. Although most of the 65 million pieces of information sent back by the probe was in the hands of the scientists responsible for the experiments within half an hour of reception back on Earth, it took two months to interpret this information. The main reason for this delay was an unexpected difficulty in interpretation due to circuit interaction between the various components. This was unfortunately most serious in the microwave and infra-red experiments. The data have still to be fully analysed, but it is not expected that the provisional results will be modified to any large degree.

As Mariner passed between the Sun and Venus, the radiometers made three very useful scans of the planet. The first went upwards on the dark side, the second downwards approximately along the terminator, that is the boundary between the dark and sunlit sides of the planet. In fact, the terminator was crossed at one point. The third scan went upwards over the sunlit side, passing very close to the point directly under the Sun.

The full analysis of the returns from the microwave experiment has still to be made, because the sensitivity of the 13·5 millimetre channel behaved in a rather unexpected manner and this has caused a delay in interpreting the information. The 19-millimetre channel, however, has indicated that the surface temperature on both the sunlit and dark sides is roughly the same. It also showed that there is very strong 'limb darkening'. This infers that the surface temperature is very hot; in fact, a figure of 800° F. has been given.

The strength of the radiation received on the two infra-red channels was more or less the same, indicating that the atmosphere above the cloud layer contains no (or at the most, very little) carbon dioxide. The temperature at the top of the cloud layer is apparently the same on both the dark and sunlit sides; it also appears to be uniform except for one local area near the southern end of the

terminator. At this point, the temperature seems to be 20° lower than the rest of the cloud. The cloud layer seems to be uniformly distributed with no breaks in it. As with the microwave experiment, there was strong 'limb darkening'. This has been explained by the fact that radiation from the centre of the disk comes from lower down in the cloud layer than that coming from the limb. The temperature of the top of the cloud is given as −60° F. but a little way in it rises to −30° F.

During the fly-by the magnetometer did not behave in any way different from that recorded during quiet periods on the journey to Venus. From this, it was concluded that the magnetic field associated with the planet, if indeed it has one, is very much weaker than that of the Earth. This result was confirmed by the ion chamber particle detector, which it was hoped would detect the equivalent Van Allen radiation belts round Venus. No such belts were detected and it was therefore concluded that Venus has a negligible magnetic field.

Mariner's picture of Venus does not fit in very well with the pictures painted from observations made back on Earth. Spectroscopic evidence indicates the presence of carbon dioxide in the atmosphere, but it may well exist in the region below the cloud layer, a region not investigated by Mariner. The surface temperature is much higher than the terrestrial observations seem to indicate. What is surprising is the lack of a magnetic field, although some astronomers had previously thought that this may be the case. Nevertheless, it had been noticed that when Venus lay between the Earth and the Sun, there was a reduction in the number of disturbances caused by solar plasma. This seemed to indicate a shielding effect due to a magnetic field associated with Venus.

The 'cold spot' detected by the infra-red radiometer has not yet been explained. It could be that the cloud is a little higher at this point and is therefore colder, or it could be due to some surface feature. Radar experiments, conducted whilst Mariner was on its way to Venus, have detected a small patch on the planet which seems to be different from the rest of the surface. It seems to be in the same general area, but because of the uncertainty of the

position of the axis of rotation, it is not possible to say whether it is the same feature or not.

A very big mystery surrounding Venus is its rate of rotation. Many values have been put forward, one of the latest being the value obtained from the radar experiments mentioned earlier. This suggests that Venus rotates in a retrograde manner relative to the Sun, but it is non-rotating relative to the stars. This would mean that the Sun would rise in the west and set in the east about 110 days later. If this is correct, many problems are created to explain the similarity of the temperatures on the dark and sunlit sides. It seems to indicate a very strong 'greenhouse effect' and also a violent circulation of the atmosphere below the cloud layer.

A very big factor for the success of the project was the very accurate tracking of the probe. Its speed was known to within 0·01 mph relative to the Earth. By noting the changes in its velocity as it passed Venus, a new figure for the mass of the planet was obtained, viz. 0·81485 times that of the Earth. No doubt, when the final figures have been declared, astronomers will have a much more accurate figure for the astronomical unit, i.e. the distance of the Earth from the Sun.

Conclusion

On 1963 January 4 at 14^h, 130 days after launch, contact was lost and the experiment came to an end. At that time the probe was 54,000,000 miles from the Earth. Thus ended the first successful interplanetary space probe. Even if its findings were not what many people hoped and even if these findings are subsequently found to be in error, its place in the history of science and technology is assured.

Selenology – or Geology Applied to the Moon

PETER J. CATTERMOLE

The Moon, since it has no atmosphere and lies in such close proximity to the Earth, has attracted the attention of great numbers of astronomers since the science received the benefit of the telescope. Indeed, it would not be an exaggeration to say that many lunar observers have a more detailed knowledge of the Moon's surface than they have of the Earth itself. With a 3-inch refracting telescope, craters but 3 miles in diameter can be resolved, and consequently a great amount and variety of features await the attention of lunar observers.

The most obvious features of the lunar surface are the vast dark maria. These contrast strongly with the bright walls of the thousands of craters surrounding them and lying on their surfaces. Long chains of small craters, rifts and mountain blocks are also prominent among the structures present on the Moon. From the earliest times in the history of observational astronomy, astronomers have indulged in a controversy as to the possible origin of the major lunar forms. One school of thought favours meteorites as the cause of the craters, whilst the other opposing school finds it expedient to reconcile them to the terrestrial volcanoes. It is the opinion of the present author that the latter mode of origin is the most likely to be proved when man sets foot on the lunar surface.

What, then, of the features to be seen on the Moon and how can their structure be explained by geological processes known on the Earth? First of all, the craters. These are the most numerous of all lunar forms and range in size from mere pits, a matter of yards across, to huge sunken formations exceeding 180 miles in diameter. A study of the larger formations reveals that structurally they are

much like the largest of Earth's volcanic 'subsidence cauldrons'. Characteristically these exhibit faulting, or collapse along their margins, this having occurred sometime after the actual eruption had taken place. This is due to the fact that such an area is quite unstable after the eruption and planes of weakness about the structure bring about the collapse of the whole by faulting, so that a vast cauldron-like area is formed. The lunar walled plains clearly show this phenomenon, the walls in most cases being quite complex in form and much faulted. Erosion by subsequent mobile lavas has in some cases also contributed to further destruction of the initial features.

Within the ramparts of the larger walled plains are found a variety of features, the great majority of which are younger in age. Presumably when the Moon was young the energy available for producing eruption features was at a maximum, and this slowly decreased as time went on. Thus the progressively younger features exhibited a gradual decrease in size, corresponding to the weaker forces coming from the interior. On the floor of Bailly, the largest of all lunar formations directly visible from the Earth, are found a number of smaller craters, some being very deep, hills, depressions, valleys and numerous minor features. The occurrence of such forms within the walled plains is interesting in that it shows a close agreement with those structures found inside subsidence cauldrons on the Earth. Often after the collapse of an earlier composite structure, a new vent gives rise to another eruptive phase in which one or more smaller craters are built up by the spilling out of lava or the throwing out of fragmentary lava, country rock and so on. Some of the seemingly isolated hill masses found may be the last remains of earlier cauldrons which were destroyed on the formation of the last caldera; others might be plugs or spines of especially viscous lava rich in silica, although this last point is rather controversial.

So far it is apparent that there seems to be an analogy between lunar and terrestrial structures. However, it has been argued that the size of the lunar walled plains is far in excess of the calderas of the Earth and so a comparison cannot be strictly made. It is true

that the larger lunar formations have diameters in excess of 120 miles, while the majority have diameters within the limiting range 25 to 60 miles. On the other hand, terrestrial calderas rarely exceed 60 miles in diameter and generally lie between 10 and 15 miles. It must be borne in mind, however, that the Moon's gravitational potential is only one quarter that of the Earth, and consequently much larger eruption features could be produced. In fact, it seems quite likely that on the whole lunar eruptions were *less* violent than those experienced on the Earth.

Another prominent feature of the lunar surface is the preferred distribution of craters and valleys in certain directions, and the occurrence of numerous small craters along the limiting walls of large walled plains. The latter phenomenon can be quite simply explained. Remembering that it is most probable that the walls of the larger formations represent lines of slippage and faulting, and knowing that eruptions occur preferentially along lines of weakness in the crust, then it is not surprising that a large number of later craters are located along boundaries of walled-plains. A case in point is the large ruined formation Hörbiger[1] (see Fig. 1) along whose south-eastern rampart is located a row of smaller craters. This continues farther east towards the adjacent smaller plain Pitatus, along whose walls are also found smaller craters and valleys. On the floor of the large formation Clavius, which lies near the lunar South Pole, is a series of craters which are seen to lie on an arc-like line of weakness. Both this series and that of Hörbiger are seen to diminish in size to the east. This decrease in diameter seems to represent a decrease in available energy-with-time as the eruptive phase passed.

On a somewhat larger scale it is noticeable that most of the lunar features can be found to be aligned along a number of intersecting imaginary lines. Around Mare Imbrium a radial alignment is evident, whilst the large groups of craters such as Arzachel-Alphonsus-Ptolemaeus and Cyrillus-Theophilus-Catharina, are seen to be aligned along great circles running north-south. Furthermore, on close examination many of the large craters are

[1] On some maps this formation is called 'Hellplain'.

seen to possess a distinctly polygonal outline. This phenomenon and the others mentioned above can be almost certainly put down to stresses to which the lunar crust was subjected. (There is an analogy here with the famous columnal basalts of the Giant's Causeway in Antrim, where hexagonal columns of rock, due to the cooling of a formerly homogenous rock mass around centres, are exposed.) If, as some scientists believe, the Moon was at some time in its history 'captured' by the Earth, then there would be one explanation for the setting up of stresses in the lunar crust. Another cause of such forces could be the gradual cooling of the Moon and

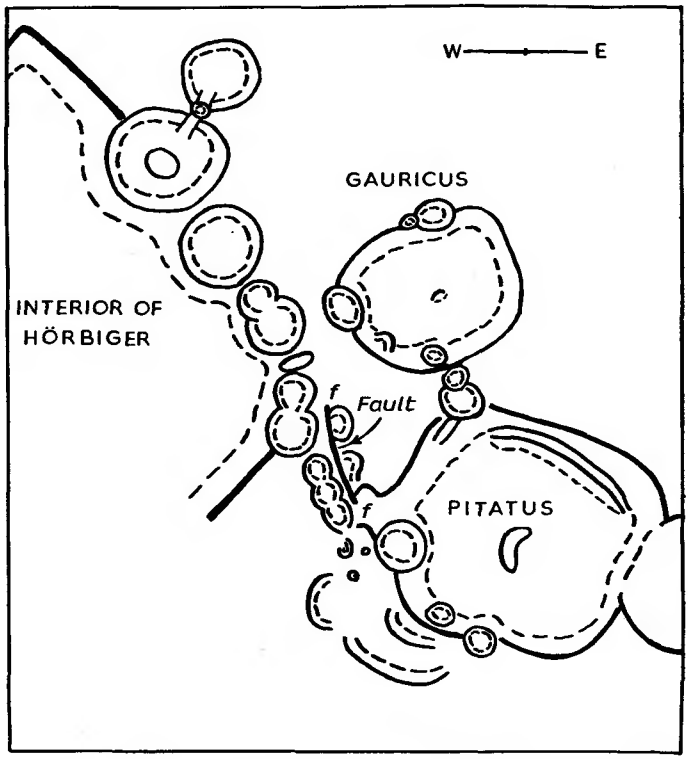


Fig. 1. *Crater series along south-east flank of Hörbiger*

the release of stress in the form of volcanic activity. This in turn could lead to gradual devolatilization of the core and the diminishing intensity of eruption as is exhibited in the lunar features. However, this point is one that is wide open for discussion at the present time.

The great dark maria, so prominent as vast plains on the face of the full Moon, contrast vividly with the bright-walled craters that have been discussed. Some, such as the Mare Crisium, are fairly regular in outline, whilst others, such as the Oceanus Procellarum, are less clearly defined and are much larger. Indeed, the smaller maria seem to grade down into the largest of the walled plains. This may point to a similar origin, although a difference in scale is implied. On the surfaces of the various 'seas' are found craters, peaks, wrinkle ridges, valleys, crater rows, domelike swellings, faults and numerous other smaller structures. The sinuous winding ridges – 'wrinkle' ridges – are found to represent the former boundaries of old walled plains which have subsequently been inundated by lavas or collapsed with the formation of younger calderas. Large craters such as Archimedes (on the Mare Imbrium) and Copernicus (on the Mare Nubium) are typical, and obviously of later date than the maria on which they stand. The borders of these vast areas are in some places defined by high mountainous ridges, such as the Apennines, the Percy Mountains and the Alps, and in others only by a change from dark 'lunabase' material to the brighter 'lunarite' material which is so typical of the crater-strewn areas.

Less prominent yet exceedingly interesting are the low, roughly circular swellings or 'domes' which after careful search can be seen to lie scattered about the mare floors. From their distribution it would seem that the mare borders are the most favoured places for them. A fine group is found between Hortensius and Tobias Mayer, east of the large terraced crater Copernicus; another lies in the vicinity of Diophantus and De L'Isle. Most of the swellings have at their summit small pits which would seem to have been formed by the feeble rising of magmatic gases characteristic of the final stages of an eruptive phase. The domes probably find an

analogy in the endogenous lava domes seen in the volcanic regions of the Earth. The apophyses sometimes found growing from the lunar features are also in accord with this view.

Numerous chain-like systems of craters exist. Generally they can be explained as having followed migrating magmatic activity along crustal weaknesses. Fissure eruptions of this calibre can be seen in Iceland (Threngslaborgir, for example). In many cases the walls of the separate components of the chain have been destroyed by later eruption in the form of the adjacent crater and partly washed down by the action of hot lava streams. As was noticed to be the case with valleys and craters, so a rough alignment of crater chains is traceable along a system of grid-like directions. The diagram (Fig. 2) shows a number of such crater rows (also known as crater valleys) near the Moon's western limb. Clearly in this case one series of craters has found a line of weakness corresponding to the rim of the plain Hagecius and another to the east side of Pontécoulant South. (To gain some idea of the scale, the well-formed crater 'K' adjacent to Pontécoulant is 20 miles across.)

Other linear valley features are not quite so easy to explain. Structurally they are long linear depressed areas and very narrow in comparison with their length. Crateriform bulges are not present and so it would seem that they do not represent the ultimate form of washed-down crater chains as described above. It rather appears, then, that they are rifts in the lunar crust which have been brought about by the stretching of the crustal layers as the Moon cooled. This does not mean to say that they are bottomless cracks; far from this; they have definite floors which are generally convex. Possibly they represent the lunar equivalents of the Earth-type 'graben'. They are undoubtedly guided by fault planes, but to what extent hot magmas rose along these planes, melting the crust underlying the rifts and incorporating blocks of country rock, it cannot be said with any certainty.

Having described most of the features found on and about the maria, it remains to provide a possible explanation for the occurrence of the maria themselves. From their very nature it appears that lava has washed their floors and faulting has played a large

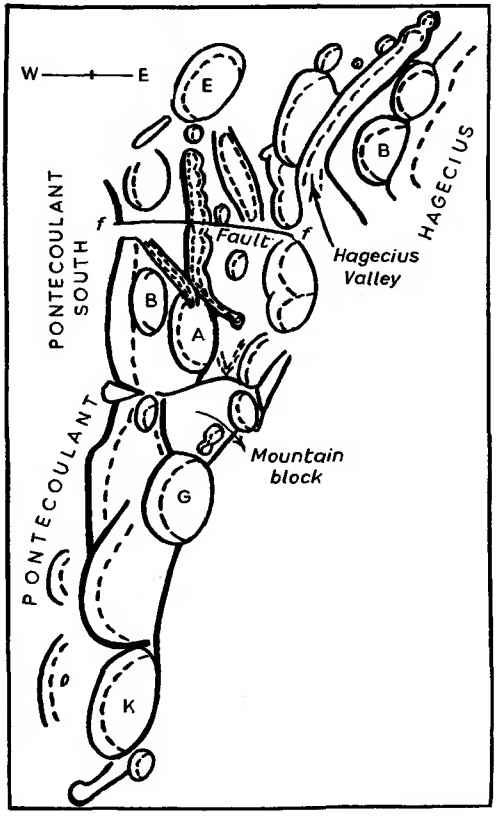


Fig. 2. Crater rows and valleys near the Moon's western limb

part in determining their boundaries. The present writer, therefore, believes them to be the ultimate form of subsidence feature on the Moon. The fact that few maria exist on the other side of the disk (viz: Russian Lunik photos) seems to indicate that the excessive stresses set up on the side facing the Earth (the Moon has a captured rotation), allowed imprisoned forces built up beneath the lunar crust to escape at a late stage in the form of tectonic activity.

Yet again this is a highly controversial point, and the reader should study other views before reaching his own opinion.

One last major problem remains to be discussed – that of the lunar 'rays'. Anyone who has seen the full Moon through a telescope will have noticed the long bright streaks radiating from such craters as Tycho, Copernicus and Kepler. When closely studied under high magnification, fine structure is revealed, and the rays are seen to consist of thousands of separate streaky patches all lying in the general direction of the whole system. Some of these stop against crater walls and mountain blocks, and this indicates that they are explosion features. The fact that a ray-free halo lies around each crater forming the centre of a ray system adds weight to this idea. Rays are recent lunar features, since they cross the smaller craters, and thus it is likely that they are the youngest features. Whether they are masses of volcanic dust sent out from their parent craters, or finely comminuted lava droplets, remains for the first space-men to find out. The Moon will hold many problems for lunar 'geologists'.

The Great Red Spot on Jupiter

W. E. FOX

The year 1964 will find Jupiter in a more northerly declination than for some years past, rendering it a favourable object for observation by observers living in the northern hemisphere.

When first seen in an astronomical telescope the planet is indeed an impressive object, its belts and zones never failing to impart a sense of wonder and delight to the thinking person with a desire to learn more about the universe in which we find ourselves. A 3-inch diameter telescope will, in good seeing conditions, reveal much on the surface of the planet, but a larger aperture is preferable if one wishes to study it in greater detail. It will be found that many spots, both dark and light, are in existence on the surface, and it has been the policy of the B.A.A. Jupiter Section, for many years now, to examine and study the motions of these features. By doing so, various drifts in longitude and changes in the appearance of the belts and zones have been detected giving rise to the differential rotation periods existing in the visible upper layers of the planet's atmosphere.

While many of these markings have their own particular interest, none has attracted so much attention as the Great Red Spot. It lies in the latitude occupied by the South Tropical zone and the south component of the South Equatorial belt, but over the years its longitude has been subjected to considerable change. In appearance it takes the form of a large ellipse, upwards of 26,000 miles along its major axis and some 12,000 miles across its minor axis, often with a strong red colour varying in intensity to pink and neutral grey, sometimes disappearing completely, though at such times its position is revealed by a large bay in the south

edge of the South Equatorial belt now known as the Great Red Spot Hollow.

The long-enduring character of the feature has been established beyond all possible doubt, but it was in the year 1878 that the attention of observers was especially directed to the Red Spot, for it was then that it assumed a prominence hitherto not recorded. From 1879 to 1882 it dominated the surface of the planet not only by reason of its great size but also because of its striking red colour – hence its name. It became so prominent that it could easily be seen in telescopes of less than 3 inches of aperture. There is no doubt, however, that it had been a well-observed feature long before 1878, for that keen-eyed observer the Rev. W. R. Dawes figured it on his drawings in November 1857, while a few years later it was independently recognized by other observers including Jacob, Baxendell, Huggins and Long.

W. F. Denning, from records of longitude determinations, computed rotation periods for the Red Spot over a number of consecutive intervals between the years 1831 and 1878 which show a close relationship to those found in more recent times. It is on record that Hooke, Cassini and others with their inferior instruments, observed a spot in 1664 and later years, which appeared in the same latitudes and had nearly the same rotation period, and to these men, in particular Hooke, must go the credit for the discovery of what has proved to be one of the most remarkable planetary markings ever seen.

If this identification is correct, then the Great Red Spot is at least 300 years old, which is, as B. M. Peek remarks, 'a truly venerable age for a feature that is manifested only in the planet's atmosphere'. According to the records of the rotation periods computed by Denning, we find a mean value of 9 hrs 55 min 32 sec in 1831–2, which gradually lengthened until the years 1856–60, when it had reached 9 hrs 55 min 38 sec, after which the period shortened to 9 hrs 55 min 33 sec in 1876–78, but by 1885–86 this had lengthened to 9 hrs 55 min 41 sec, at which the Red Spot, with small variations, remained reasonably steady until the year 1909.

Some of the early observers put forward the suggestion that

they were observing a volcano erupting on the solid surface of the planet causing a red glow in the clouds above the seat of the eruption, but a study of the rotation periods reveals that, far from being related to some landmark on the solid nucleus, the Red Spot had a motion of its own, moving backwards and forwards in longitude, and, in fact, between the years 1831 and 1885, when its rate of rotation had been less than 9 hrs 55 min 40 sec, it was actually drifting round the planet in the direction of rotation. In 1872–73, when the period of the Red Spot reached the time of 9 hrs 56 min 31 sec, the rate of drift was actually $-7°$ per month. From 1885 onwards to 1909 the rate of drift varied from 0° to $+1°{\cdot}5$ in the direction opposite to the planet's rotation. An object with such a wandering tendency must surely be floating in the upper layers of the planet's atmosphere. One writer has referred to the Red Spot as a floating island moving more slowly as it breaks through the clouds to higher levels, lagging behind, as it were, as the planet rotates on its axis, a fact fully confirmed by observations over many years.

During the apparitions of 1900 and 1901 a remarkable feature developed, destined, as it proved in later years, to have a profound influence on the motion of the Red Spot. A series of dark humps could be seen projecting from the south edge of the South Equatorial belt, one of which became very prominent early in 1901. On February 28 of that year P. B. Molesworth recorded that this spot had become connected by a greyish filament stretching across the South Tropical zone with a dark streak on the South Temperate belt. This filament became rapidly distended in longitude, and brilliant white spots developed at its preceding and following ends, the portion between the white spots becoming somewhat darkly shaded. It was to this shaded portion that the name 'South Tropical Disturbance' was given, and it was found that the whole of this disturbance had developed a rotation period of 9 hrs 55 min 20 sec. It was at least 90° from the longitude of the Red Spot, which had at that time a rotation period of 9 hrs 55 min 41 sec. It was clear to the observers of that day, that the new feature if sufficiently long lived, by reason of its more rapid motion, would

certainly overtake the Red Spot in due course. This indeed happened in June 1902, when the preceding end reached the following end of the Red Spot.

Interest was centred upon the manner in which the two objects, existing in the same latitudes, would react upon each other. What actually occurred was quite unexpected. Instead of obliterating the Red Spot and the Hollow in the south edge of the South Equatorial belt, the whole of the latter became surrounded by the dusky shading of the Disturbance, the preceding end of which could be seen re-forming at the preceding end of the Red Spot. Within three months the South Tropical Disturbance, the whole of which totalled a length of 90° of longitude, had passed round the Red Spot. This was the first observed conjunction of the two features.

The second and third conjunctions occurred in 1904 and 1906, by which time the South Tropical Disturbance had shrunk in length somewhat, and its passage from end to end of the Red Spot and Hollow was accomplished in about 14 and 12 days respectively, though it must be admitted that some of the observations are somewhat uncertain. The fourth, fifth and sixth conjunctions took place in 1908, 1910 and 1913–14, and the observations establish the fact that the material composing the South Tropical Disturbance was again transferred rather rapidly from the following to the preceding ends of the Red Spot, but this phenomena was much protracted at the seventh conjunction which continued from 1917 to early 1920. At this time the Disturbance had increased its length considerably, reaching a maximum of more than 190° of longitude. The conjunctions described had the effect of shortening the rotation period of the Red Spot until 1924, when it reached the shortest recorded in the twentieth century of 9 hrs 55 min 32 sec.

Describing the eighth conjunction, which became only partial, the Rev. T. E. R. Phillips (then Director of the B.A.A. Jupiter Section) wrote 'The motion of the Red Spot had become so accelerated that it was actually receding from the preceding end of the Disturbance and its rotation period was definitely less than that feature', a state of affairs which continued during the apparition of 1925. From 1926 to 1928 the Disturbance became invisible

and when seen again in 1929 was found to have extended to some 220° of longitude, while the rotation period of the Red Spot had resumed its more usual rate; at the same time the motion of the preceding end of the Disturbance became accelerated.

The ninth conjunction began in 1928, by which time the Disturbance had reached a length of 240°, but its effect on the motion of the Red Spot was now considerably reduced, the two features remaining in conjunction until 1935, when the Disturbance again became invisible, all trace of it being finally lost in 1939–40. From 1909 to 1939 the Red Spot had actually drifted two and a half times round the planet in the direction of rotation, but after the disappearance of the South Tropical Disturbance it began to drift against the rotation, having now, in 1962, reached a point in longitude some 300° from where the backward drift began – more than three-quarters the distance round the planet.

We naturally ask ourselves 'Was the rapid motion of the Red Spot in the middle of the nineteenth century due to a similar South Tropical Disturbance having a similar influence to that so well recorded during the first part of the twentieth century, and is it part of a periodic phenomenon not yet fully understood?' If so, surely future generations of observers will again witness these events. Long-period schemes of observation over many decades may be necessary to supply the solution to the problem.

That the South Tropical Disturbance is likely to be renewed was suggested by the events which began in 1955. B. M. Peek, a former Director of the Jupiter Section, observing in the early morning of 1955 September 19 with a 3-inch telescope, observed a filament across the South Tropical zone which reminded him strongly of Molesworth's observation of 1901. The feature grew in length and at maximum extended over 42° of longitude, and after some variations exhibited a rotation period not unlike that of the old Disturbance. The new feature was observed with much interest and it was conjectured that the earlier events might be repeated; in fact, it appeared that the stage was set in readiness for this to happen, but the new Disturbance was short-lived and it disappeared in 1957, having never reached conjunction with

the Red Spot, which, of course, showed no sign of being affected.

Other phenomena which have a profound effect on the Red Spot are the outbreaks of activity on the South Equatorial belt which occur from time to time. These are too numerous and complicated to describe in detail, but a brief summary of the events will suffice to record the appearance of these eruptions. The south component of the belt is often so faint as to be almost invisible, a state of affairs which may continue for an indefinite period. A revival begins by the outbreak of a small spot between the components from which other spots begin to move in opposite directions, those on the south edge moving in increasing longitude, while those on the north edge move in decreasing longitude. After a period of some weeks the two streams begin to pass each other on the opposite side of the planet on which the eruption began. On reaching the vicinity of the Red Spot, the spots on the south are usually deflected northwards round it, eventually forming the well-known Hollow in this portion of the belt. A scene of great turbulence develops and eventually the Red Spot begins to fade, losing its characteristic appearance. It is then that it appears to sink below the upper cloud layer and often entirely disappears, being replaced by a pale oval bounded on its north side by the Hollow. It is only when the great activity on the South Equatorial belt is subsiding that the Red Spot makes its reappearance.

Photography has been brought into use for recording the various Jovian features. As far back as 1927, W. H. Wright of the Lick observatory made a real contribution to our knowledge of the planet by a series of images obtained in light of different wavelengths from ultra-violet through the spectrum down to infra-red. There is a distinct reduction in the size of the disk of the planet as the prints reach the longer wavelengths with their deeper penetration of the atmosphere, while on the shorter wavelengths from ultra-violet to blue the Red Spot shows strongly in the upper layers. The method has been followed in more recent years by others, particularly J. H. Botham of Johannesburg, whose ultra-violet photographs in 1960 show the Red Spot very strongly, while

exposures in infra-red light taken within a few minutes of the ultra-violet ones show absolutely nothing of the Red Spot, surely a reliable method of recording the atmospheric levels of various features.

During the early months of 1955 Dr. B. F. Burke and Dr. F. L. Franklin of the Carnegie Institute of Washington were engaged upon making a radio survey of certain portions of the sky known to contain radio sources. One of these was the well-known Crab Nebula and some other feebler sources. In addition to these 'noises', they obtained some signals from a hitherto unknown source whose strength at times greatly exceeded anything they had received previously. They eventually traced the signals to the position occupied by Jupiter, which was in that part of the sky at the time. Having located the source of this new radio emission, astronomers were curious to find out whether any special localities on the planet were responsible. This proved a difficult problem, but Dr. C. A. Shain of the Commonwealth Scientific and Industrial Research Organization at Sydney, N.S.W., who carried out much research in the matter, suggested that the larger number of 'noise' bursts followed a rotation period close to that of some white ovals on Jupiter's South Temperate zone, with some evidence that at times the reception of signals is very strong when one of the white areas is in conjunction with the Red Spot. It is not known whether the Red Spot itself is an independent emitter of radio waves, but later investigations still show a strong tendency for emissions to occur when it is crossing the disk of the planet.

There is much research to be done, and observers, each in their own particular field of work, be it visual, photographic or radio research, may eventually throw some light on what is probably one of the most remarkable and interesting planetary objects – the Great Red Spot on Jupiter.

Telescope Mountings

HENRY WILDEY

Telescope mountings fall into two classes: altazimuth and equatorial. The altazimuth is the type of mounting that one usually finds with telescopes set up on seaside promenades or piers, where they serve admirably, as the telescope is required to swing up and down or from side to side as the viewer switches from the passing battleship to the girl on the beach.

Celestial objects, however, show slow rotation round a point in the northern hemisphere of the sky close to the Pole Star, so that they traverse great arcs at the celestial equator. To follow a star or planet therefore means that one has to keep moving the telescope from east to west, and at the same time raise its altitude if the star is rising in the east or lower the altitude if the star is on the western side of its southing point. As these two movements have to be made simultaneously, they are not easily carried out with smoothness; there is the added difficulty that an astronomical telescope gives an inverted image, and the beginner may be somewhat confused by finding that the instrument has to be moved in the direction opposite to that which is expected. When an object is low in the field, for instance, it has to be brought to the centre by raising the angle of the telescope instead of dropping it.

With even slight experience, it is surprising how quickly one becomes used to these motions, and the altazimuth mounting should not be discarded out of hand, even though it has obvious disadvantages.

For cheap refractors, the usual and worst type of altazimuth mounting is the compass joint. This tends to be jerky in operation, and is very often coupled with the pillar and claw table stand, which is a highly undesirable feature. Such telescopes are presumably

intended to be used on a table at a window. No serious observer would even consider doing anything of the sort – and tables small enough to be carried outdoors are never rigid enough to be satisfactory, as well as being inconveniently low.

Better refractors usually adopt the tripod stand, together with what is termed a trunnion mount – in which the telescope is supported between two extended arms which rotate upon the tripod. In the more elaborate models, this rotation is controlled by a worm and wheel hand-control, while a steadying rod leads off from the tripod to the eye-end of the telescope, thereby adding stability and also providing another form of hand-control slow motion. Slow motions are essential when using high powers, since it must be remembered that the slightest tremor will be magnified several hundred times when the instrument is being used.

The trunnion mounting can be quite well adapted to reflectors; my own 12½-inch was thus mounted. A good point, too, is that the eyepiece always remains in a comfortable and accessible position. I found that I could make variable star observations much more speedily than when using an equatorially-mounted telescope, and it was not at all difficult to follow the planets when making drawings of them.

For a small Newtonian reflector – a 6-inch, say – the mounting can be almost identical with that of the refractor, but the tripod need only be short, since the eyepiece is at the top end of the tube. This is, indeed, one of the most convenient features of a Newtonian reflector, since it makes for comfortable viewing; it is easy to turn the telescope to the zenith or overhead position, whereas with a refractor the observer may well have to lie almost flat (unless, of course, the tripod is extremely high). Some owners of refractors make use of star diagonals, but these cause loss of light as well as producing confusing reversals in the orientation of the image.

My 12½-inch reflector had a permanent mount. The column consisted of a tube of sheet iron, riveted up, though an old oil-drum would have served just as well if I had had one available. I hunted round a car-breaker's yard, and found an old lorry flywheel with a toothed edge and a small-diameter starter cog to engage

with the teeth; I also managed to find three ordinary ball-races of about 2 inches diameter. (The total expenditure was only a few shillings.) A hole was dug, and filled with concrete, with a few short pieces of iron rod pushed in to the centre. The roll of sheet-iron to form the column was put over these rods, and was then filled to the top with a mixture of three parts sand to one of cement, with rather more water than one would generally use. The flywheel with its short length of shafting was then pushed down into this soft mixture, and, after careful levelling, was allowed to set for several days; eventually it became as firm as a rock. A short piece of straight shafting on the upper side of the flywheel was used as the central pivot, and the weight of the two oak beams supporting the telescope was taken up by the three ball-races, which were bolted on to an iron ring attached to the stout cross-member under the beams. The beams were left rather long on the side opposite to the telescope, in order to reduce the amount of counterweight required. It should always be remembered that it is important to make the mounting, as well as the telescope, so that it is in a state of balance without having to rely upon undue friction.

The second basic type of mounting, the equatorial, makes use of an axis of rotation inclined toward the celestial pole (the point around which the sky appears to revolve; the inclination is of course equal to the observer's latitude). It is easy to see that with an equatorial, the telescope will keep any selected object in view with one movement only. A clock drive may be attached to the polar axis, so that the telescope moves at a rate just sufficient to compensate for the diurnal motion of the sky and keeps the object in view. A refinement is to fit a circle on to the axis, divided into 24 hour-divisions – the right ascension circle – while the other movement, the altitude, can be checked by a similar circle, marked in degrees and known as the declination circle.

Circles are very useful if the telescope is permanently set up; they may be helpful in finding Venus in the daytime, for instance, and are invaluable for locating faint objects which are not readily visible. Yet they are of little use for portable telescopes, and my personal view is that they are sometimes used more than is strictly

necessary. It is far better to find a faint object by using a good star atlas rather than to rely wholly upon setting circles.

There are various types of equatorial mountings, though all are, of course, based upon the same principle. The most common, probably, is the German. This has the usual inclined axis; from a T-shaped bearing another shaft extends at a right angle, one side of which takes the telescope, while the other side is fitted with a counterweight to maintain balance. Nearly all refractors are mounted in this way, and most amateur telescope-makers automatically adopt it when setting out to make an equatorial mount. Yet while the German works well with refractors, it is by no means so satisfactory with reflectors, as it requires precision engineering, coupled with a very large declination axle. Many amateurs make this bearing far too thin, with a considerable degree of overhang. It is claimed that in such a case, the shaft is still quite strong enough to take many times the weight that it actually has to carry. This may be true; but strength should never be confused with stability – and it is stability which matters most. Nothing is more frustrating than to try to observe details on, say, Mars or Jupiter, when the telescope is quivering in the breeze. Stability may be obtained by giving large bearing surfaces and a high degree of inertia, together with plenty of weight. In fact, the heavier a mounting, the better it is likely to be.

Next let us consider some mountings which are not suitable for refractors, but which may be recommended for reflectors of all sizes. First there is the English type – familiar to all astronomers, since it is used for the 100-inch reflector at Mount Wilson. Here, the telescope is pivoted inside a large yoke, inclined at the correct angle of latitude, and supported by a pier. This mounting is extremely suitable for amateur telescopes, as it requires no precision engineering whatsoever. The tall pier should have a base going well down into the ground; it must extend below the frost line, and must have sufficient 'roots', as otherwise it will tend to shift when leaned against by a well-meaning friend. (This is no exaggeration; I have known it happen). A small concrete stump is needed to support the yoke at the other end, and this, along with

the tall pier, should have a halved Plummer block bolted on to the top, so forming the bearings for the short axle stubs which extend from each end of the yoke.

The yoke itself may be made of wood, provided that it is substantial enough. For a 12-inch reflector I have known wooden railway sleepers to serve excellently. Slotted angle-iron is another suitable material. However, in my view the best material is a casting made of three parts sand to one of cement mixture; reinforcing iron does not really add much to the strength, and may well have the effect of breaking up the material in which it is embedded. Always provided that the mounting made in this way is massive enough, it will have plenty of strength. Concrete does not vibrate so readily as metal, and for this reason is to be preferred. To form the yoke, a rough wood and fibre-board mould can be constructed; a piece of wood or a metal mandrel which has been wrapped round with several turns of wax paper is inserted at each end, and when the mandrels are removed from the hardened concrete they will form the holes for the axles of the yoke. Two similar holes are made in the centre of each side, to take the bearings of the telescope tube.

If one selects the right time of year to carry out the operation, there is no reason why the casting should not be carried out in the ground instead of in a specially-prepared mould. This involves levelling off a patch, and carefully digging out the required shape with a spade and trowel, setting in the mandrels and then filling in to ground-level with the concrete mixture. After a sufficient period of time (probably at least a week) the surrounding earth may be dug away, but the casting should be left for a few days before being finally taken up from the ground, as it may easily crack if it is still in the so-called 'green' condition. If it should break, there is, unfortunately, nothing to be done except smash it up and use it to make a rockery. The materials themselves are extremely inexpensive, but a failure means an annoying waste of time, and it is obviously unwise to try to hurry the operation.

If it becomes necessary to drill small holes in any of the concrete components, the best instrument is a twist drill with a tungsten

carbide tip, easily obtainable from any good tool-shop or builder's merchant. The hole is then plugged with any of the patented materials sold for this purpose, and the screw inserted in the usual way. Any holes can naturally be 'touched up' with a trowel and a little cement mixture.

After a much longer time, perhaps as much as a year, the casting may be given several coats of paint to improve its appearance. The reason for delay is that cement is alkaline, and unless it is weathered out completely it will cause rapid deterioration of any paint applied to it.

Next let us consider the fork mounting, which is not unlike the yoke, but has the yoke cut in half so that there is now no upper portion or tall pier. This means that the bottom axle must be lengthened and made considerably stouter, since it is now supported only at the base. The telescope tube is pivoted between the prongs of the fork. The mount should be made so that the mirror end is able to pass right through the arms. If so, the telescope can reach the area of the celestial pole, which is an unavoidable 'blind spot' with an English equatorial.

With a fork mounting, the difficulty is to make the lower bearing to the right length and proportion. This is avoided with the last type of mounting to be considered here: the Foucault. With the Foucault, the polar axis is supported at its end by a single ball or thrust race, and broadens out into a large disk with a machined edge which is supported by two ball-races. Two stout arms are bolted on to the face of the flat disk, forming the arms between which the telescope is mounted. In my personal view, the Foucault is the best possible type of mounting for a reflector. It is low and compact; the points of balance do not overhang; and if the arms are stout, there should be no troublesome vibrations.

To construct a Foucault, the first essential is to obtain a large flywheel, complete if possible with a short length of shaft. The flywheel should have at least twice the diameter of the telescope mirror. Flywheels of such a type are used for driving machinery by means of belts, and the edge will be quite smooth unless the wheel has been badly exposed to the weather. The arms can probably be

bought complete as a couple of extended plumber brackets, and may be either bolted or screwed on to the flywheel; alternatively, they can be prefabricated. The base of the mounting is a triangle, made up from ordinary angle-iron, and welded; it may, of course, be constructed from slotted metal fixed together by nuts and bolts, with projections extending from it to take the ball-races which support the main weight.

To make a clock drive for a Foucault-mounted telescope involves using a large toothed bronze wheel, which should be fitted on to the shaft a short way down from the flywheel, the teeth engaging with a single start worm in stainless steel if possible. Do not make the mistake of having the teeth too fine in the hope of getting a better drive. It is much better to have deep-set, rather coarse teeth, so long as the worm is a really good match. There is no need to allow for throwing the worm in and out of engagement, provided that teeth of this type are used. If everything is well-balanced, the toothed disk need be only in slight frictional connexion with the shaft to impart the drive to the telescope, and at the same time allow the instrument to be swung around to different objects without any noticeable drag or strain. This is not so when fine teeth are used, since any attempt to move the instrument will tear the teeth hopelessly unless they are completely disengaged. This, again, is no exaggeration; I have seen teeth so fine that they could be compared with those of a nail-file!

A small electric motor, such as that used in a gramophone, serves quite well for the actual drive, since the required power is extremely small owing to the tremendous gearing-down. Gear-boxes are obtainable to effect the major part of this reduction, but I have seen efficient drives which have been made entirely from Meccano gears and worms mounted on short spindles between metal plates.

Finally, it is important to remember that no matter what type the mounting may be, or how well it is constructed, it is always difficult to prevent a long tube from being shaken in gusty weather, and so it is wise to consider the tube at the same time as the mounting. By making a skeleton instead of a solid tube, the effects

of wind-resistance may be largely overcome. It is also prudent to make the telescope of fairly short focal length, say *f*5 to *f*6; if higher magnifications are needed, they may be obtained by using a Barlow lens, which in any case gives better results than very short-focus eyepieces.

All in all, the making of a telescope mount is just as important as the making of the telescope itself. If the mounting is unsteady, or defective in any other way, the instrument will never be able to be used to its full capacity – and this vital point is all too often overlooked.

Astronomy and Navigation

HENRY BRINTON

To many of those who have not been caught by its fascination, astronomy appears to be a highly theoretical science, which purports to tell us a great deal about the outer reaches of space, but can tell us next to nothing about the Earth a few miles under our feet. This attitude is hardly softened when astronomers, on theoretical grounds, double the already unimaginable distances overnight. And yet, from the very earliest times, the study of heavenly bodies has led to severely practical results.

We do not know when man first took to the water and fashioned boats which, from mere floating logs, developed into craft capable of voyaging long distances out of sight of land. It is, however, certain that it was very long ago indeed that the discovery was made that Sun and stars could be used to point the navigator's way over the trackless waters. It is believed that bees certainly, and migrating birds almost certainly, use the Sun for navigational purposes. Primitive man, we may be sure, had the same ability to some degree.

It was in about 200 B.C. that Eratosthenes used the basic principle of astro-navigation to measure the size of the Earth. He knew that at the summer solstice the Sun was vertical at midday at the town of Syene, and that Alexandria was nearly due north of Syene. He also knew the distance between the two towns. By measuring, with the aid of a shadow cast by a pillar, the distance of the Sun from the zenith at noon on the day of the summer solstice at Alexandria, he was able to estimate the circumference of the Earth. What is more, his estimate is believed to have been a very good one – much better than the approximation which made Columbus mistake the West for the East Indies.

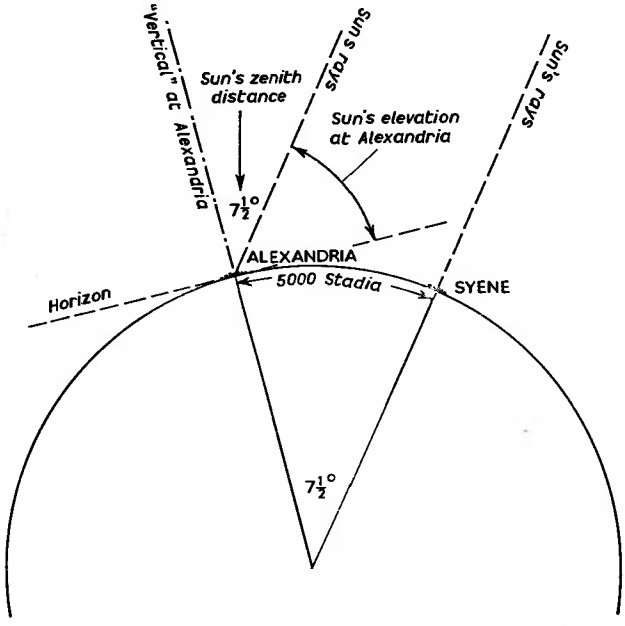
Eratosthenes' method was about as simple as anything could be. Since the rays of the Sun can be taken as parallel, it is obvious that the angle by which the Sun was lower than the zenith at Alexandria must be the same as the angle at the centre of the Earth subtended by the two towns. He made this angle $7\frac{1}{2}°$ and the distance between Alexandria and Syene 5,000 stadia. It follows that 5,000 stadia is to the circumference of the Earth as $7\frac{1}{2}°$ is to 360°, the Earth, therefore, would be 240,000 stadia in circumference.

Astro-navigation is founded upon this simple principle. Yachtsmen and others who have attempted to master the subject have sometimes been given the impression that navigation is a highly abstruse and difficult art. In principle, nothing could be further from the truth. The complexity and the difficulty of working an actual sight only arise because of the many allowances which have to be made for variable factors and the need for exact calculation by spherical trigonometry.

Anyone possessed of a good-sized globe and a pair of dividers could work out a position in a few moments, to a degree of accuracy which would not be good enough for bringing a ship into port, but which would have seemed a miracle to Columbus. During the war, I fixed the position of a convoy to within about fifteen or twenty miles with nothing to aid me but observations of the times of sunrise and sunset. The tools employed were the naked eye, a child's school atlas, *Whitaker's Almanack* and a wrist-watch checked by the B.B.C. pips on the radio. The last was the one advantage I possessed over the early navigators. Latitude is child's play; but for longitude accurate time is needed.

If we look back at Eratosthenes' experiment, we shall see that there were three measurements involved and that, if we know any two, we can at once deduce the third. Given the circumference of the Earth and the zenith distance of the Sun, one can at once calculate the distance between Alexandria and Syene.

For us, the matter is even simpler than this. We measure distances due north and south not only in miles but sometimes in degrees of latitude. It is apparent from the drawing that $7\frac{1}{2}°$ is the difference in latitude between Alexandria and Syene. But, since



we know that at the summer solstice the Sun is 23½° north of the equator, the latitude of Alexandria, using Eratosthenes' figures, must be 23½° + 7½°, or 31°N. – which is almost exactly right.

There is, however, nothing unique about the position of the Sun at the summer solstice. We can, by looking at the Nautical Almanac, find the declination of the Sun north or south at any time on any day of the year. If we want to find out latitude, all we have to do is to measure the elevation, and hence the zenith distance, of the Sun when it is at its maximum, and this tells us how many degrees we are north or south of the place where the Sun is at the zenith at that instant. By adding or subtracting the declination of the Sun, as the case may require, we can at once find our latitude.

The only qualification to this is a comparatively trivial one. If

we are very far east or west of Greenwich, and do not know the correct time, we may be slightly out in our reading of the Sun's declination. Using a rough approximation, however, the error will be slight.

The Sun is not the only star which we can use in this way. Indeed, other stars are more convenient, because their declinations do not alter from day to day. If the Pole Star were exactly at the celestial pole, all we should have to do would be to measure its elevation, and that would be our latitude. In exactly the same way as we used the Sun, we can take any star, measure its zenith distance when it is in transit, add or subtract its declination, as is appropriate, and that is our latitude.

This was the method used by the early explorers. By the use of the astrolabe, a primitive form of sextant, they could determine latitude from the Sun or a convenient star. The latitude of the destination would be known, and all that was required was to steer well to the west or east of the destination until its latitude was reached, and then turn and sail along that latitude. One was bound to arrive at the right place in due course.

Given access to the correct time, longitude is nearly as easy to find as latitude. A moment's reflection will make the point clear. In order to find the moment of transit of a star, including the Sun, it is not necessary to know the time. All that one has to do is to take a series of elevation measurements until the reading is a maximum, which occurs at the moment of transit.

In obtaining a fix in both latitude and longitude, the Sun, or any convenient star, is observed when it is not at its maximum elevation. In these circumstances, nothing can be known about the exact point on the globe where the star in question is at the zenith point without also knowing the exact time. We can calculate our distance from the zenith point just as easily; but this is singularly little use unless we know where the zenith point is. The case of a latitude reading is merely a special case, because we know that the Sun, or other star, is due south of us, as well as knowing its declination, and therefore know its exact zenith point without knowing the time.

Let us turn back to the drawing of Eratosthenes' experiment and generalize it. We can leave out all directions and still deduce much the same facts. For every degree we are removed from the Sun's zenith point, *in any direction*, the Sun will appear one degree from the zenith. This is really all that the drawing is showing us. If we substitute for the word 'Syene' 'Zenith point of the Sun' and for 'Alexandria' 'position from which zenith distance of the Sun is measured' and leave out the '5,000 stadia', the drawing is equally valid, though more general.

As I have said, the Sun is not the only star which can be used in this way. It is convenient because its height above the horizon can easily be measured, whereas other stars are apt to be visible at a time when the horizon itself is invisible. At dusk and dawn, however, bright stars can be used.

A star other than the Sun circles over the latitude which is given by its declination. A knowledge of the time will tell one over what point of longitude it is at zenith at any given moment, and this point can be marked on a map, chart or globe. The same is true of the Sun, except that the latitude must be corrected for its changes in declination. These positions are given in nautical almanacs and can easily be looked up.

Having measured the elevation, and deduced the zenith distance by subtracting from 90°, and marked the position at which, at that instant, the star being used is at zenith, the next step is obvious. The zenith distance tells us how many degrees we are away from the zenith point. If we are using a globe for rough navigation, we can then set a pair of dividers to that number of degrees, as measured between latitude circles. If we then trace with the dividers a circle, with the centre at the zenith point, we know that we are somewhere on the circle, which is called a circle of equal altitude.

By measuring the zenith distances of two stars at very close intervals if we are on a moving ship, or at our leisure if we are stationary, we get two intersecting circles and must be at one of the points of intersection. For most purposes, this will be sufficient. In practice we are not likely to be so ignorant of our position as not to know which of the two points of intersection is the right one. If,

however, we are totally lost we can always measure a third star, and the three circles will only meet at one point.

Practical navigation is, of course, not done in this simple way with a globe. A chart is used, and various allowances are made, as well as using calculation in place of simple measurement.

A sextant needs to be corrected for the dip of the horizon, that is to say, the height of the eye above the horizon; but, for practice, a home-made astrolabe can be used, and this makes its own artificial horizon. Alternatively, for those who are not handymen, a bubble sextant can be used, though it requires a good deal of practice to become proficient in the use of this instrument. A further correction has to be made for refraction; but, if a star not too far from the zenith is used, the effect can be ignored. If the Sun is the chosen body, it is easier to measure from the lower limb than to try to find the centre point. In this case a correction of about a quarter of a degree has to be made for the semi-diameter.

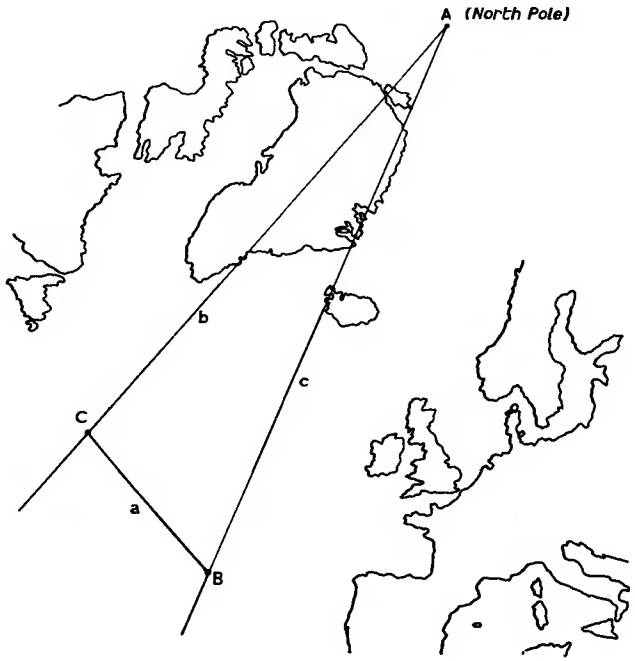
These adjustments are relatively simple. The main toil of practical navigation is working out a solution instead of measuring it on a globe. The method is simple enough in theory, but requires elementary spherical trigonometry; four-figure log tables, moreover, are not accurate enough, so the scope for error is sufficiently wide.

The method used in principle can be seen from the drawing. Let C be the position of the ship, A the pole, and B the zenith position of the star used. Then c is clearly the polar distance of the zenith point; that is 90° minus the latitude, and a is the zenith distance of the star, as measured.

From dead-reckoning since the last fix, the approximate longitude of the ship will be known. To begin with, one takes the angle A as being this longitude less the longitude of the zenith position. It is required to find b, which is the polar distance of the ship, i.e. its latitude subtracted from 90°. This is given by the equation:

$$\cos a = \cos b \cos c + \sin b \sin c \cos \mathrm{A}$$

Having worked this out, one can mark the position deduced on the chart. This is the position of the ship if the assumed longitude



is correct. The process is then repeated, assuming a slightly different longitude, and deriving a slightly different latitude. This point is also marked on the chart and a line is drawn passing through the two points and extended a little in both directions. Though, for practical purposes, one draws a straight line, the points fall theoretically on the arc of a circle of equal altitude; but, on the scale of charts used in practice, the error is extremely small and is ignored.

As with the circle of equal altitude which we traced out on the globe, this line on the chart will not tell us our exact position, only that we are somewhere on it. Generally, however, it is sufficient to correct a dead reckoning position. If it is not, a second reading can

be taken with a second star, and a second line drawn, the position of the ship being at the point of intersection. Alternatively a second reading can be taken with the same body later on, and the first line adjusted for the movement of the ship during the interval. When the Sun is being used, this is necessarily the method employed.

Recently, extensive tables have been worked out, for a selected number of celestial bodies, which are so comprehensive in their information that very little calculating is necessary – it is not even an advantage to be able to identify particular stars. Beyond this, and especially for planes, a great deal of navigating is done by electronic aids which have no connexion with astronomy. Even using stars, telescopes can now be made to lock automatically on to quite faint stars in daylight, and do most of one's navigation for one.

In spite of all these modern developments, however, there will always be times and places at which these aids are not available, and a knowledge of the principles of astro-navigation will be required for a long time to come.

Whatever the future may bring, it is a fact that a study of the heavens has guided man in his travels for thousands of years. When we take to space travel as part of the ordinary course of our daily lives, the one thing which is certain is that a wide and precise knowledge of the motions of celestial bodies will be an absolute requirement for the safety and convenience of the cosmonauts.

The Surface of Saturn

H. N. D. WRIGHT

Since the advent of telescopic astronomy with Galileo in the early seventeenth century the planet Saturn has been an object of particular interest in that it provides us with a fascinating spectacle which so far as we can observe is unique among celestial bodies. To Galileo, with his pioneering but very imperfect telescopes, Saturn presented a considerable problem when it came to explaining the cause of this strange new phenomenon to the satisfaction of his sometimes very critical students. He may have made an inspired guess in his later life as to the reason, but the riddle was finally solved by Christian Huygens, using improved optical equipment of his own design. About the mid-seventeenth century he was able to demonstrate that the slow-changing, peculiar appearance of Saturn was due to the presence of a vast, flat ring which encircled the planet, inclined to the plane of its path around the Sun. The attention of these early observers was therefore concentrated upon deducing the nature of this fantastic appendage concerning what was then the most distant known planet. Indeed, even if they had so wished, it is doubtful if their telescopes would have been equal to the task of investigating the surface appearance of the globe of Saturn. Cassini, a contemporary of Huygens, is thought to have been the first to record some surface markings. From the work of the few observers who possessed instruments of a sufficiently high standard, it became evident that the surface of Saturn was characterized by dark belts parallel with the equator and the plane of the rings. These were similar to the belts visible on Jupiter, a much easier observed object, but less dark and conspicuous.

Very little was contributed in observations of the global features from this period until that great and celebrated observer, Herschel,

examined the ringed planet with his powerful reflecting telescopes in the latter half of the eighteenth century. He it was who really roused interest at this time in probing the nature of the planet and rings, with the aid of these very fine telescopes which he was producing. Firstly he was able to say that the belt markings were of a variable nature, indicating that we were probably looking at cloud formations in some kind of atmosphere. Observational proof was then supplied that the outer part of the globe was indeed gaseous, by his careful study of what was seen on occasions when one or other of the moons of Saturn was due to pass behind the body of the planet as viewed from Earth. Direct evidence of the airless nature of our Moon is provided by the behaviour of stars when occulted. As they pass from our view, the effect is instantaneous, as though someone had snapped off a switch. The effect of occultation of a bright object by Saturn is quite different, as Herschel observed. Not only did the brightness of the occulted moon fade away slowly, with marked fluctuations at times, but it was seen to 'hesitate', as it were, on the limb of the globe for some minutes after it should theoretically have disappeared. This was due to the light being refracted or 'bent' in passing through the outer layers of the Saturn atmosphere. Recognition of discrete markings on the globe, in the form of patches and spots, revealed that the planet rotated fairly rapidly, and by further shrewd observation Herschel made an estimate of the rotation period which is remarkably close to the value adopted at the present time. Also the considerable flattening or compression of the globe through the polar diameter was established and very carefully measured by him. All this aside from his valuable discoveries and observations concerning the ring system and satellites! Those who make a study of the magnificent Saturn today owe a great deal to the patient work of the great Sir William Herschel, for the very considerable store of knowledge which he established.

Direct observation since then has largely consisted of confirmation and refinements in measuring these various characteristics of the body of the planet. During the present century, however, it has been possible to employ another very valuable technique to permit

an analysis of the atmosphere of Saturn – the use of the spectroscope in conjunction with very large telescopes. Space does not allow a detailed description here, but briefly a spectroscope is an instrument which enables us to sort out the components making up the total visible light from a given source, in terms of standard wavelengths. Many substances can be identified readily from the characteristic pattern or, to use the correct term, spectrum of light which they produce, on comparison with spectra produced under laboratory conditions. The Moon and planets shine by means of the 'borrowed' light of the Sun, and what we normally see in the spectroscope is merely a fainter replica of the Sun's spectrum. The dark lines against the band of continuous colour denoting the absorption of certain radiations by gases in the outer layers of the Sun is faithfully reproduced, along with those introduced in passing through the atmosphere of Earth. It was noticed in the early part of this century that when the light reflected from Saturn is examined in this way, dark bands are seen obscuring certain regions of the spectrum, which can have been introduced only during the passage of the light through the outer atmosphere of Saturn. Many years ensued before laboratory researchers were able to show that the effect was due to the light having encountered a considerable quantity of methane gas on its journey. This is a compound of hydrogen and carbon, which we know on Earth as marsh-gas, and is familiar to the miner as the deadly 'fire-damp', which, owing to its combustible nature, has been the cause of many pit disasters.

The presence of this gas on Earth is a consequence of decomposing vegetation, but on the Giant Planets such as Saturn is the result of the combined effect of very low temperature and great mass enabling these objects to retain virtually the whole of their original gaseous surroundings. There is no reason to doubt that all the major planets in the Sun's family had a common origin, and that therefore Earth also once possessed such a dense, unpleasant atmosphere. As a consequence of the much smaller mass of Earth, the lighter gases in this original atmosphere have leaked away steadily into space, leaving us with our present gaseous shroud

consisting almost entirely of nitrogen and oxygen, the latter constituent being enriched in supply by the large amount of vegetable growth. It came as no great surprise when these hydrogen compounds were discerned in the atmosphere of Saturn. The total amount of material involved, or in other words the mass of the planet, could be estimated quite accurately by careful observation of the motion of the satellites, all the nine now known having been discovered before the end of the nineteenth century. This mass proved to be 95·2 times that of the Earth. Yet the volume of Saturn is no less than 763 times that of our planet! Obviously Saturn is made in the main of much lighter material than the terrestrial globe, and hydrogen, the lightest of the elements, fills the bill very nicely. Unfortunately, free hydrogen does not reveal itself in the spectrum of the light reflected from Saturn, but only when it has combined with carbon to form methane (CH_4), and to a lesser extent, with nitrogen to form ammonia (NH_3).

One of the most popular and widely accepted theories for the probable constitution of Saturn is the model proposed by Dr W. H. Ramsey of Manchester University, in the early 1950s. He believes that possibly as much as 70 per cent of the mass of Saturn consists of hydrogen in some form or other. A fairly shallow atmosphere in proportion to the size of the planet is anticipated, consisting largely of hydrogen and helium, with the addition of a good percentage of methane and a trace of ammonia. At a depth of only a few hundreds of miles in this atmosphere the hydrogen would be compressed into a solid state, after reaching a consistency more like that of a liquid, viscous ocean than an atmosphere. At a distance of about 12,000 miles from the periphery of the globe toward the centre, the pressure is sufficient to cause a transition from the solid to the metallic state of hydrogen. The central core of the globe probably contains some of the heavy elements such as form the body of our planet Earth. This, with the great proportion of metallic hydrogen, gives a probable density at the centre of Saturn of about 1·9 times that of water. The mean density of Saturn, which is calculated from our direct knowledge of the size and mass of the globe, is only 0·69 times that of water.

Saturn is therefore by far the lightest of the planets per unit mass.

So much, then, for the reasons, both theoretical and observational, for believing that in the case of Saturn we are looking at a very different kind of world as compared with planets such as Earth and Mars. Nevertheless, we do observe this familiar characteristic of a cloaking atmosphere, though sufficiently deep and dense to prevent observation of whatever kind of solid surface might exist.

It was suggested in the early days of telescopic observation in astronomy that the giant planets, particularly Jupiter and Saturn, might have some radiation output of their own, to account for the brightness of these objects, and the atmospheric turbulence and upheaval which is observed. However, modern measurements of temperature and radiation levels of these planets, together with theoretical considerations, makes it almost certain that the belt markings, spots, and other detail seen are due to the action of the Sun, in just the same way that the depressions, anti-cyclones, hurricanes, and great weather movements in Earth's atmosphere are generated in the first place by the solar 'heat-engine'. So there is a surprising, and in some ways unexpected, similarity in the behaviour of the clouds of Earth and Saturn. Though the clouds of Saturn may be of quite different composition to those we are accustomed to, yet they serve to trace out the movements in the atmospheric envelope under the influence of temperature differences and the rotation of the planet. The rotational velocity of Saturn is high, the 'day' being only $10^h\ 14^m$ at cloud level at the equator. This swift rotation and strong central concentration of mass combine to produce the pronounced flattening of the globe through the poles of rotation.

Anyone who has studied Saturn at all will have heard of the Great White Spot of 1933. This was discovered by Will Hay, otherwise famous in the entertainment world, in August of that year, on the Equatorial zone of Saturn. This marking was followed for over five weeks by the leading planetary observers of the time, and its behaviour was typical of other spots or discrete markings

which have been seen on the planet on rare occasions. After discovery, the spot lengthened steadily in the direction of the planet's rotation, and the preceding end became blurred and indistinct after only a few days. This carried on until the 'spot' extended almost half-way round the equator of Saturn. At the same time the rotation period of this particular feature shortened. This and similar instances seem to indicate that the outer parts of the atmosphere rotate faster than the lower levels, or in other words, there is the semblance of a wind in the direction of rotation. As the material forming the spot moves upward in the atmosphere, so it is carried forward round the planet parallel to the equator. Some spots in the temperate regions of Saturn have been seen to accelerate to a period as short as $9^h\ 55^m$, or about equal to System II on Jupiter. Doubtless they also have risen in the atmosphere, and have steadily advanced with respect to the normal cloud-level. The belts are also formed and maintained most probably in this manner.

One cannot escape an intriguing comparison here with the so-called 'jet streams' in the atmosphere of Earth. These powerful east-moving winds have become known since the inception of high-altitude flight, and have been used by east-bound aircraft to establish record times in transit from one continent to another. Hence they are accelerated in the direction of Earth's rotation! Situated in median latitudes north and south of the equator, the jet streams are found by their particular temperature characteristics and if they were delineated by clouds, as they sometimes are over part of their path, they would appear from space rather like the N. and S. Equatorial Belts of Saturn do to us. There is even a lesser sub-tropical jet stream, which could appear as a fainter belt marking closer to the equator. Further careful observation and measurement of the latitudes of the belts on Saturn will establish in time whether they move toward or away from the equator in rhythm with the seasons, as these fast-flowing streams in Earth's upper atmosphere do.

Lastly, what is the prospect for future space-travellers who may choose to visit the planet Saturn? Certainly they would be advised

not to try to find the solid surface of the globe, beneath the deep and dense atmosphere, for the pressure at the real surface of solid material is estimated to be many times that at the deepest points in Earth's oceans. A much more interesting and healthy way of 'taking in the view' would be to float in the atmosphere at about cloud-level by using containers of de-compressed hydrogen or helium. Protection would be needed from the very low temperature at this level of around −120°C., but weight would present no problem, things being much the same in this respect as they are at Earth's surface. The force of gravity on Saturn at upper atmosphere level is only a little greater than that on the Earth's surface. Our 'Saturn balloonist' will now be carried around by the rotation of the planet, and we must assume that he has been wise enough to avoid being placed in the region beyond latitude 63 degrees N. and S., roughly corresponding to the Arctic and Antarctic Circles of Earth. Here the Sun would not be seen for long periods, up to almost 15 of our years in extreme cases, and the glorious spectacle of the ring system would be below the horizon, permanently hidden from view. These conditions follow naturally from the fact that the axis of rotation of Saturn is inclined to its orbital plane a little more than that of Earth, around 27 degrees, the planet takes 29½ years to orbit the Sun, and the ring system is in the plane of the equator.

Imagining the choice of latitude to be his, a far better idea for our explorer would be to position himself somewhere in temperate latitudes, say about 40–45 degrees N. or S. This would place the ring system at a pleasing angle of view for detailed study, forming a great arch spanning the heavens, and undergoing fascinating transformations of light and shade during the Saturnian year. He would experience a 'day' of about 10½ hours, and for many Earth-years the Sun would be placed behind the rings, its light being delicately veiled to a varying degree, brightening as it traversed the so-called ring divisions. The Sun in the Saturn sky would be a tiny, brilliant object, having only one-ninth of the diameter which it presents to us, or between 3 and 4 minutes of arc. Also it could never be entirely eclipsed by the rings as seen from these latitudes,

but would continue to show quite well through even the thickest portions. For a region just a few degrees N. and S. of the Saturn equator only would the rings be able to completely obscure any celestial body, including the Sun. During the summer in a particular hemisphere, with the Sun well above the plane of the rings, they would form a broad silvery band, against a rather bright sky background due to scattered light in Saturn's considerable outer atmosphere.

At night the portion of ring visible when the Sun is above the ring plane to the observer would bear a dark wide gap as though a section were missing. This is the effect of the intensely black cast shadow of the globe obscuring the Sun's light from the opposing part of the ring system. This would reach a maximum in extent when the Sun lies in the plane of the rings, on two occasions in the Saturn year. At midnight there would be a brilliant arc of ring reaching up from east and west horizons, with an apparently clear gap in the S. or N., according to the hemisphere in which the observer was placed. On closer inspection, it would be realized that only the brighter stars are visible to the unaided eye in this region of sky, due to the filtering effect of the ring particles. Closer to the equator, of course, the rings seen at a shallow angle would cause a strip of sky to be quite blank of stars. The appearance of the rings at night during the winter in either hemisphere would be fascinating indeed, with the Sun shining through the ring from below. Thicker portions of the rings would be outlined as bright and slender concentric arcs, and the effect would be one of very subtle tones as the angle of the sunlight to the ring plane varied, imagining each ring particle to behave like a tiny replica of our Moon, passing through a slow succession of phases. Then there would be the spectacle of several of the moons of Saturn moving at varying speeds across the night sky, against a background of constellation patterns which would appear just the same as we see them from Earth.

Our seemingly great leap through space from the orbit of Earth to that of Saturn is infinitesimal when compared to the distance of even the nearest stars comprising these familiar groups. Merely to

have this privilege of a wonderful new outlook on the solar system from the surface of the most magnificent planet in that system should be ample reward for a journey from Earth which would take at least about 4 or 5 of our years. However, we must leave our hardy adventurer with a problem to consider – how to build up a velocity of 22 miles per second to escape from the gravitational hold of the planet and return home!

Planetary Nebulae

COLIN A. RONAN

'Planetary nebulae' was the name given by William Herschel in 1785 to objects which appeared in his telescope as tiny disks of light with a hazy or nebulous edge. They looked greenish in colour and not so very different in appearance from the distant planet Uranus, which Herschel had discovered four years earlier. Yet, whatever magnification he used, the objects always showed an ill-defined edge, just as if they were nebulous disks of a 'much-condensed, luminous fluid'. In brief, Herschel found it impossible to decide exactly what these objects were, and he adopted the term planetary nebulae simply because it described what he saw. We still use the same name, even though we know, as did Herschel, that the objects are certainly not planetary.

Yet if planetary nebulae are not planets, and not straightforward gaseous clouds – what Herschel would have described as 'luminous fluid' and called 'nebulae' pure and simple – what are they? Why do they present primarily a greenish appearance, and why do they appear round or oval, instead of being spread irregularly over a patch of the sky? The answer is that all planetary nebulae are associated with a bright central star, and the hazy disk is composed of gas surrounding the star. Indeed, we shall not be very far from the truth if we think of a planetary nebula as a star with an immense gaseous shell of atmosphere extending around and spreading outwards in space for millions of miles.

Some hundreds of planetary nebulae are known, but all are so far off that none are bright objects in a telescope. Every single one is only a dim hazy patch at first glance. It was, of course, this fact that caused Charles Messier to include some of the brighter ones in his great catalogue of nebulae; a catalogue which he drew up for

the sole purpose of helping comet observers, so that they should not become confused between nebulae and the dim hazy patch of light which a comet shows when it is still some distance from the Sun. So if we try to observe planetary nebulae, we shall be examining very faint objects indeed. The most spectacular of them is probably the 'Ring' nebula, M57 (number 57 in Messier's catalogue), which is to be found between Beta and Gamma Lyrae. It has a central star which is not visible at all in a small telescope, and a bright ring of gas, rather like a bright round doughnut. The central star of the 'Owl' nebula (M97) is also quite invisible in all but a large telescope, although its faint hazy disk which appears about the size of Jupiter can be seen. It was Lord Rosse who coined the name 'Owl' for the nebula, because in his giant 72-inch telescope the disk seemed to have two slightly darkish patches, one each side of the centre, and just like the dark patches made in its white face by the eyes of a barn owl.

The very dimness of planetary nebulae means that every observer will record an object differently, depending upon his own eyesight. In consequence, the only really satisfactory way of studying these objects is to use photographs made with very large reflectors. And, of course, astronomers want to know the nature of the gaseous envelope surrounding the central star. Is it moving, and if so how? Of what gases is it composed? How hot is the central star, and why does the surrounding envelope glow? To answer these and many other related questions requires the use of the spectroscope, but this is not easy, because of the dimness of the nebulae. However, using newly designed spectographs attached to the 100-inch and 200-inch telescopes has recently provided a great amount of new information.

The central star of every planetary nebula so far observed is certainly extremely hot. In fact, recent studies have definitely established that their temperatures are never less than 25,000°C. Some are a type of star known as class W or Wolf-Rayet type, after the two French astronomers who first examined stars like this in detail. They are bright, very hot stars which radiate their energy away at terrific rates, and may well be surrounded by expanding

shells of gas. However, the Wolf-Rayet stars at the centre of planetary nebulae seem to be different from normal stars of this type; they are dimmer and although bluish stars, show every evidence of being old. The second type of star to be found at the centre of planetary nebulae is also believed to be old, containing, like the other type, more helium than hydrogen. These are the O type, bluish-white stars, which are again intense energy radiators. Both the W and the O stars which are found in all planetary nebulae are small, and it seems likely that they are blue or white dwarf stars. In consequence they will be very massive – with their material so intensely packed together that a matchbox full of it would weigh something like a ton! Surrounding these stars is some gaseous material which is at an amazingly high temperature, due to the intense radiation from the central star. Thus some recent measurements have indicated that 100,000°C. is not unusual for the nucleus of a planetary nebula, and one nebula, NGC 7662 (number 7662 in the New General Catalogue of nebulae) may, it is believed, have a nucleus temperature of 200,000°C.

The gases which surround the star and form the nebular part of the object, are very widely spread out indeed. In fact, their general density is much lower than what we would call a vacuum on Earth, with only something like 16 atoms per cubic inch. Perhaps we can best see what this means if we imagine taking the air from an ordinary toy balloon and spreading it out so that it filled a balloon which is 45,000 miles in diameter – that is a balloon $8\frac{1}{2}$ times as large as the Earth. Only then would the air be dispersed in a way equivalent to the gas in a planetary nebula.

Tenuous the gas may be, but it is spread over a considerable volume of space. Most planetaries have diameters of about half a light-year, although some of the larger may possess diameters of two light-years or more. However, we must treat these figures with reserve. They refer to the observed diameters of the nebulae, but there are reasons to suppose that the gases may well extend farther out than this. Whether or not they do depends really upon the way in which the planetaries shine, and this we must now consider.

The gas of a planetary nebula shines because of the star at its

centre. As we have seen, such a star is very hot and has an absolute magnitude of between 0 and -1, that is about 100 times as bright as the Sun. Even so it has become clear that most of its radiation is not in the visible region of the spectrum at all. In fact, it has been found that these W and O type stars are more efficient radiators of ultra-violet than of any other radiation, and so the gaseous envelope of a planetary nebula is constantly receiving an intense stream of ultra-violet light. This radiation is of high energy, and consequently it has a marked effect on the gas atoms. It causes them to become ionized, that is to say it causes them to lose one or more electrons, and much of the radiation we observe is due to the re-combination of these free electrons with the ionized atoms or ions. The really remarkable thing about all this is the degree of ionization which takes place. As we might expect, the most intense amount occurs close to the central star, and is so great that atoms of the gas neon, for instance, which is hard to ionize, are ionized four times – in other words, lose four of their electrons. Farther out the ionization is a little less, but even so oxygen atoms have been stripped of two electrons, and neon is in a similar state. In the most distant regions, singly ionized oxygen is still to be found. These ionized atoms all emit radiation in the visible part of the spectrum. The Danish astronomer, Bengt Strömgren, believes that all we can photograph is the ionized gas of a planetary nebula. Should there be neutral (unionized) gas lying farther out from the central star and well beyond the ionized envelope, then he believes that this will not be observed. If he is correct, our estimates of the diameters of planetary nebulae must all be too small and require correction.

Ionized gas atoms are not the only source of visible radiation from the nebulous material. Because the gas is so thinly spread out over so large a volume of space, many of the electrons which are torn away from their parent atoms by the ultra-violet radiation will move freely about before re-combining with the ionized atoms. These electrons may lose energy when passing close to an atom, even though they do not re-combine with it. Such a loss is observed as visible radiation, and so adds to the light we received from the

nebula. What is more, the very tenuous conditions of the gas result in some atoms remaining in a kind of temporary state as far as their energy is concerned. Only after an appreciable fraction of a second will such atoms return to normal, emitting radiation as they do so. In brief, then, the atoms of the gas of a planetary nebulae undergo much disturbance due to the ultra-violet radiation from the central star: as a result they emit visible radiation.

The shape of planetary nebulae varies widely. Besides the more normal kind of ring and disk types, there are those in which the surrounding nebula is egg-shaped or even more elongated. The 'Dumb-bell' nebula in the constellation of Vulpecula (the Fox) is an excellent example. Some investigators believe that an irregular shape is more frequent and more likely, and it has even been suggested that some of the regular ring and disk nebulae are really elongated clouds viewed from one end. Certainly it now seems clear that the gases are not evenly distributed about the central star. In some areas they are more closely packed than in others, while under high magnification in a very large telescope the surrounding material often seems to be composed of many strands or filaments.

None of the planetary nebulae are close, and their distances are in general thousands of light-years from us. Moreover, they are far from being evenly spread over the sky. Instead, they show a very definite concentration towards the central area of our own Galaxy, spreading all round it in the shape of a flattened disk. If we think of our own Galaxy as shaped rather like two soup-plates placed mouth to mouth, then we must picture the planetary nebulae spread out over a small plate placed at right-angles, and so stretching above and below the soup-plates. The closer to the centre of the Galaxy we get, the more planetary nebulae there are, and by far the greatest number are to be found concentrated within a distance of 5,000 light-years from the centre. Beyond this distance they rapidly thin out.

How the planetary nebulae were formed, no one knows. Most investigators seem agreed that the gaseous material has been ejected from the central star, for it is always observed to be moving

outwards. Even the fact that so many planetary nebulae are irregular in shape does not alter the case. The pressure of the radiation from the central star and unevennesses in the gas itself would soon lead to distortions of the gas envelope, even if it were originally shaped like a perfect sphere.

One is tempted to suppose that every planetary nebula is, perhaps, the result of a nova-explosion of a dwarf star late on in its life. Yet more evidence about the way in which stars evolve and about planetary nebulae themselves is really needed before we can achieve more than a guess.

Harrison, Maskelyne and the Longitude Problem

P. S. LAURIE

It is just two centuries since a solution was found to the problem of finding a ship's longitude at sea by practical methods.

As early as 1714 'An Act for Providing a Publick Reward for such Person or Persons as shall discover the Longitude at Sea' was passed. This Act appointed Commissioners, who constituted the Board of Longitude, and laid down that if a method was considered by these Commissioners to be of general use and practicability, then the inventor would be 'Entitled to a Reward, or Sum of Ten Thousand Pounds, if it Determined the said Longitude to One Degree of a great Circle, or Sixty Geographical Miles; to Fifteen Thousand Pounds, if it Determined the same to Two Thirds of that Distance; and to Twenty Thousand Pounds if it Determined the same to One half of the same Distance'. It was stipulated that half of any reward was to be paid when a majority of the Commissioners agreed that it would be useful to navigation, the other half to be paid when the method was proved by a voyage between Great Britain and the West Indies.

The two methods most likely to succeed in finding the longitude were, first, the construction of an accurate timekeeper, which could be carried by a ship, giving the time of a standard meridian of longitude, for example, Greenwich. Local time could be obtained by fairly simple observations. As the longitude of the ship would be the difference between the meridian on which she lay and that of Greenwich, this method would lead to a simple solution. At this period, however, there was no timekeeper capable of keeping anything remotely like accurate time at sea.

The second possibility depended on the navigator having

accurate positions of the Moon and stars. If these were known, tables could be calculated, giving the Moon's angular distance, as observed on a standard meridian (again, say Greenwich) from selected fixed stars. If, by means of a suitable instrument, these distances could be observed from shipboard, then the corresponding Greenwich time could be obtained from the tables. Even though the sextant, or, more strictly, quadrant at first, was invented independently by Hadley in this country and Godfrey of Philadelphia in about 1730, no accurate tables of the positions of the Moon and stars were available in suitable form.

For more than two decades after the formation of the Board of Longitude no reasonable method was suggested, but in 1737 John Harrison (1693–1776), son of a Yorkshire carpenter, proposed a promising plan for a marine chronometer. Financially assisted by the Board, he constructed over the years three large timekeepers, the third being completed in 1757. At this stage Harrison notified the Board that he intended to enter it for the £20,000 reward and also intended to construct a fourth and much smaller watch.

Harrison's genius produced his fourth chronometer, often referred to as H4, in 1759; it is probably no exaggeration to say that this was (and remains) the most significant watch in the world. As far as Harrison was concerned, the time was fast approaching when the solution of the longitude problem was in sight.

A supporter of the lunar distances method had already entered the field in 1756, when, at a meeting of the Board on March 6, tables of the Moon's places were submitted by James Bradley, the Astronomer Royal. A professor at Göttingen University, Tobias Mayer, had based these tables on his improved theory of lunar motion and had sent them to Bradley for his consideration. The Astronomer Royal laid them before the Board with strong recommendations as to their probable use in determining longitude, as a result of which it was resolved to have three of Hadley's quadrants made for shipboard observations and that three naval commanders should try out the practicability of the lunar distance method.

Harrison finally decided to stake his reputation and the prize on chronometer No. 4 alone; elaborate precautions were consequently

taken both by Harrison and the Board to ensure a fair test. On 1761 March 12 it was decided that Harrison's son, William, should accompany the watch (with, of course, an official observer appointed by the Board) on H.M.S. *Deptford* from Portsmouth to Jamaica. Sailing on November 18, the ship touched at Madeira and arrived at Jamaica on 1762 January 21. Time had been determined by the equal altitudes method at Portsmouth and the same method was used on arrival in the West Indies. Allowing for H4's known rate, it was found that the error only amounted to 5 seconds slow, or $1\frac{3}{4}$ minutes of longitude (less than one geographical mile at the latitude of Jamaica).

On the face of it, the longitude problem was solved, and Harrison was entitled to the full £20,000, but when the results of the trial were presented to the Board on June 3 the Commissioners had their doubts as to whether the watch's wonderful performance was mere chance, and only awarded Harrison an advance of £2,500, £1,500 to be paid immediately; the other £1,000 would not be paid until a second trial. At the same meeting a petition was laid before the Board by Nathaniel Bliss, Bradley's successor as Astronomer Royal, on behalf of Mayer's widow (the professor having died).

The beginning of 1763 saw Harrison little nearer his goal, although further evidence had been presented to the Board by at least one naval commander who had tried out lunar distances in 1757.

It was at this stage that Nevil Maskelyne (1732–1811), whose name will always be associated with navigational aids, entered the lists. After being ordained in 1755, he had collaborated with Bradley on the problem of refraction and soon gained a reputation as an able astronomer and a practical observer. Soon deciding that the Church was not his real bent, he devoted much time to astronomical matters, was elected F.R.S. and selected by the Royal Society to observe the Transit of Venus on 1761 June 6 at St Helena, the primary object of this expedition being to determine the solar parallax. Sailing in the East Indiaman *Prince Henry* under the command of Charles Haggis (not H.M.S. *Sea Horse* as

usually stated), Maskelyne stayed ten months on the island and made many observations of longitude there as well as on the voyage.

Now, in 1763, he came out fully on the side of lunar distances, which he introduced in his privately printed publication 'British Mariner's Guide' and in which he strongly advocated the publication of an astronomical ephemeris.

At a meeting of the Board held on 1763 August 4 Harrison again requested that No. 4 only should be used on the second trial. Arrangements were then made, as on the previous occasion, for time determinations at Portsmouth and Jamaica. Reflecting telescopes (probably Hadley's) and equal altitude instruments were again agreed upon as the most suitable means of accurate observations. As a result of a further petition on behalf of Mayer's widow (this time by the University of Göttingen and the Royal Academy of Sciences there) the Board decided that whoever went out to Jamaica to make the necessary observations of longitude should also make observations of the Moon's motion to test the accuracy of Mayer's tables. On being asked whether he would undertake this, Maskelyne refused to go to Jamaica on health grounds, but said that he would go to Barbados or any other place. To this both Harrison and the Board agreed; Maskelyne was to have £300 for his trouble and was eventually accompanied by Green, assistant to Bliss at the Royal Observatory, who was made up to Purser of a fifth-rate warship (for purpose of payment) and granted his expenses. William Harrison and his H4 were to sail in H.M.S. *Tartar*. Maskelyne and Green made the voyage in H.M.S. *Princess Louisa*, the former as chaplain of the vessel, sailing earlier than H.M.S. *Tartar* in order to set up the field observatory at Bridge Town, Barbados, for the purpose of redetermining the longitude and checking H4 on arrival. This, and making observations on the voyage for testing Mayer's tables, was Maskelyne's first duty; it is sometimes said that he sailed with H4 to record its performance. As can be seen, this was impossible.

Maskelyne noted in his journal: '. . . (Monday) May 14 (1764). Early this morning Mr Harrison brought his Timekeeper

on shore and I took equal altitudes of the sun's limbs, noting the time by it as follows. . . . Timekeeper 4^h 1′15″·53 faster than Mean Time by the meridian of the observatory.'

On the return voyage from Barbados, the observations were laid before the Board on 1764 September 18.

Maskelyne was paid his £300 and £242. 8*s*. 10*d*. expenses; in addition he was allowed to sell the materials from the observatory building in Bridge Town to pay for his passage and for the freight charges on the instruments. Later, owing to the materials only realizing £18. 10*s*. 4*d*., the Board paid him a further £87. 12*s*. 3½*d*. to make up his expenses.

By January 19 the observations had been reduced by four independent persons and H4 was found to have an error of 38 seconds fast in seven weeks, corresponding to less than 10 geographical miles. Maskelyne, to be officially appointed Astronomer Royal in about a fortnight's time, was entrusted with Mayer's tables.

Harrison, on his watch's second success, now asked the Board for a certificate to enable him to receive the full reward. On 1765 February 9 the Commissioners declared themselves 'unanimously of the opinion that the said Timekeeper has kept its time with sufficient correctness and without losing its longitude in the voyage from Portsmouth to Barbados beyond the nearest limit by the Act of 12 of Queen Anne, but even considerably within the same'. They stipulated, however, that the principles of the watch should be disclosed, although they did request Parliament to make up the money already advanced to £10,000 (excluding the advances for improvements) and pay the balance 'on proof being made to the satisfaction of the Board that his method will be of common and general utility in finding the longitude', in other words, that similar watches could be readily made.

At this moment of half triumph and half frustration for Harrison, Maskelyne presented a carefully prepared and far-reaching memorial to the Board (of which he was now a Commissioner by virtue of being Astronomer Royal). In it he stated his case for lunar distances, supported by evidence of considerable weight.

On his voyage to St Helena and back he had observed the distances of the Moon from the Sun and fixed stars and, by using Mayer's tables, made his longitude determinations with errors of 'not more than a degree'. He had (on the Board's instructions) repeated these observations on the recent voyage, had made Barbados within half a degree and the Isle of Wight on his return within 16 minutes of arc. Strongly urging the general publication of Mayer's tables, he stressed the need for an ephemeris, supporting his claim by the evidence of four East India Company Commanders. These officers, who were examined by the Board, had used the principles laid down in 'The British Mariner's Guide', and stated that their longitude determinations agreed 'within a degree, seldom a greater error, each observation taking up not more than four hours' time to find'. When questioned, they were unanimously of the opinion that 'if a Nautical Ephemeris was published, this Method might be easily and generally practised by Seamen'. The Board, impressed by this combined onslaught, resolved that Mayer's tables should be printed, that his widow should be awarded a sum not exceeding £5,000 and that Parliament should be asked to 'give a reward to persons to compile a Nautical Ephemeris and for authority to print the same, when compiled, in order to make the said lunar tables of General Utility'.

Before the Board met on 1765 May 28 an Act had been passed authorizing the payment of £3,000 to Mayer's widow and the construction of an ephemeris. At this meeting it was reiterated that Harrison must disclose the principles of H4 before being paid any part of the second half of the reward, while Maskelyne and the professors of astronomy on the Board were asked to consider a plan for the production of the ephemeris.

This all occurred on a Tuesday and by Thursday, May 30, the plan was laid before the Board; it was immediately approved and Maskelyne instructed to find 'proper persons to perform the calculations'. These were engaged within a fortnight and it had also been decided to print 2,000 copies of Mayer's tables, reduced to the meridian of Greenwich. One pair of calculators (Israel Lyons and George Witchell, the latter Headmaster at the Royal Naval

Academy, Portsmouth) were to calculate the almanac for 1767, while that for 1768 was to be prepared by John Mapson and William Wales. These four were to receive £70 each for their services, Maskelyne supplying the necessary books and tables.

By the spring of 1766, Witchell's own 'General Tables of Refraction and Parallax' had been printed, as had Mayer's tables, and the ephemeris for 1767, under its title 'The Nautical Almanack', was on sale. The time which had elapsed between the presentation of Maskelyne's memorial to the Board and the Nautical Almanac becoming a reality was thus little more than a year. Its popularity was immediate; within a further year the almanac was officially distributed to 'all the chief ports in Great Britain and Ireland, New York and principal places in America'; within three years masters of all Royal Navy ships were to take courses at the Royal Academy, Portsmouth, in the use of the Nautical Almanac and Hadley's quadrant and expected to obtain a certificate.

Harrison, meanwhile, had not been able to persuade the Board that he had proved his case entitling him to the other half of the £20,000. The wrangle dragged on and the elderly conqueror of the longitude problem was to see H4 tested at the Royal Observatory for ten months and a copy made by Larcum Kendal before he was able to obtain some support from George III in petitioning Parliament. At this the Board's opposition collapsed and the remainder of the reward (less £1,250 in advances) was paid in 1772.

Maskelyne received no lump sum for his part in the practical solution of the problem, but he did receive an additional salary as superintendent of the Nautical Almanac until his death in 1811, and lunar distances continued to be published until 1906.

In spite of Harrison's charges that Maskelyne was seeking monetary reward, this seems highly improbable, as does the accusation that during the trial of No. 4 at the Royal Observatory the chronometer was deliberately subjected to high temperatures in the midday sun. To do this Maskelyne would have had to treat his Transit instrument in the same way (both were in the same room) and he was too able an observer to do that.

On the other hand, Maskelyne was in a strong position to

influence the Board of Longitude. From 1765 he was a Commissioner as a consequence of being appointed Astronomer Royal and rapidly became scientific adviser to the Government. He had considerable private means, and his brother Edmund held high office in the East India Company (this no doubt explains his witnesses, whom he called in to support lunars from time to time); his brother-in-law Robert, Lord Clive, had been created a peer in 1762 and a Knight of the Bath in 1764. Clive, then a popular hero, was on leave in England before being reappointed Governor of Bengal.

The Seven Years War had ended in 1763, Britain having gained almost more from the Treaty of Paris than from any other treaty in her history. Canada was secured, additional territories gained in the West Indies, and France had recognized British dominion in Bengal and the Carnatic. With an expanding overseas trade and shipbuilding greatly on the increase, this did indeed seem the appropriate moment for Maskelyne to launch what was to become the greatest single aid to navigation of all time.

Acknowledgement is made to the Astronomer Royal for his permission to use the records of the Royal Greenwich Observatory.

Editorial Note: Harrison's four chronometers have always been treasured at the Royal Observatory (now the National Maritime Museum), but recently H4 has made its third voyage across the Atlantic. On 1963 March 8 an impressive little ceremony was held at the British Embassy in Washington, D.C., when the British Ambassador handed over Harrison's fourth chronometer to the U.S. Naval Observatory on loan for one year. This beautiful instrument is shaped like a watch, but is rather more than 5 inches in diameter. The copy made by Larcum Kendal, which is referred to in Mr Laurie's article, was used by Captain Cook in his voyages of 1772–5 and 1776–9, and is also preserved at Greenwich.

The Short-period Comets

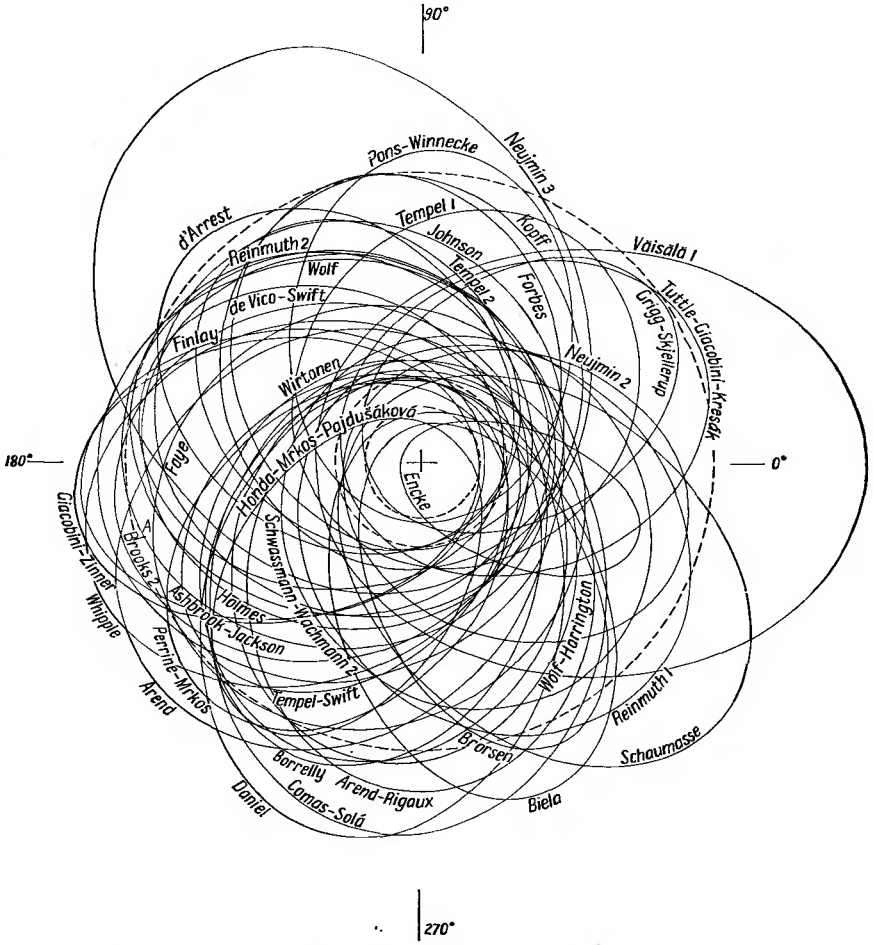
J. G. PORTER

It is usually a surprise to the ordinary reader to learn how many comets are seen each year. In the five years 1958 to 1962 no less than 42 comets were under observation; of these, 17 were new discoveries, while the remaining 25 were all short-period comets whose returns had been predicted with sufficient accuracy for them to be recovered. The greater number of these recoveries – 18 out of the 25 – were made by one astronomer, Dr Elizabeth Roemer, who uses the 40-inch reflector of the Flagstaff Station of the U.S. Naval Observatory. Miss Roemer endeavours to keep track of all comets – especially those fainter than magnitude 17 – and it is largely due to her efforts that we have been able to maintain our records of these insignificant objects in recent years. There are few observers with such skill and experience, and there are few other telescopes with time to spare for this class of work.

A short-period comet, usually represented by the symbol P/, is to be regarded as one whose period is comparable with those of the planets; a period of 200 years is considered a suitable upper limit. The periods actually range from the 3·3 years of P/Encke (with a doubtful 2·3 years for P/Wilson-Harrington of 1949) up to the 164 years of P/Grigg-Mellish, which was seen in 1742 and 1907. We have on our lists 94 such comets, of which 55 have made more than one return to perihelion. They are mostly very faint objects, of very little interest in ordinary telescopes, but they offer a constant challenge to the computer.

As a class, they differ from the majority of comets in having a more restricted range of inclination to the ecliptic. Whereas the majority of cometary orbits may be inclined at any angle, so that almost a half of them have retrograde orbits, those of the short-

period comets are mainly of small inclination, and only seven (one of which is a very doubtful case) travel in the retrograde direction. The elliptical orbits in which they revolve are quite eccentric, so that the perihelion distance is small, but the aphelion distance may



After Richter, 'Nature of Comets'

be quite large. There are, however, two comets which are exceptions to this rule, and which have orbits so nearly circular that they are like minor planets, and are seen every year at opposition. Comet Schwassmann-Wachmann (1), discovered in 1925, has an orbit which lies entirely between those of Jupiter and Saturn, and it has the smallest eccentricity (0·131) of any comet, and the largest value (5·54) of perihelion distance. Comet Oterma travels in a smaller orbit between Mars and Jupiter, the eccentricity being only 0·144.

The most famous of all these comets is, of course, that of Halley. Halley, who was a friend of Newton, and had been largely responsible for the publication of the famous *Principia*, was one of the first to realize the full value of the new laws of gravitation. He investigated the history of the appearance of comets, and computed their orbits, and was struck with the fact that the orbit of the comet of 1682 (which he had himself seen) was similar to those of Apian's comet of 1531, and the comet seen by Kepler and Longomontanus in 1607. He also linked these with the comets of 1456 and 1305, and was thus led to the idea of periodic comets, this particular example having a period of about 75 years. He made the first rough estimates of planetary perturbations, and the first prediction of the return of a comet:

> Hence I think I may venture to foretel, that it will return again in the Year 1758. And, if it should then so return, we shall have no reason to doubt but the rest may return also: Therefore, Astronomers have a large field wherein to exercise themselves for many ages, before they will be able to know the number of these many and great Bodies revolving about the common Centre of the Sun, and to reduce their Motions to certain Rules.

Halley died in 1742 at the age of 85. Sixteen years later, the comet returned as he had foretold, and it is to honour his name that we attach it to this fine comet. More accurate predictions were made before the actual return by Clairaut and his collaborators (the work taking more than two years); predictions for the 1835 return were made by Rosenberger and others, and that for 1910 by

Cowell and Crommelin. The comet is next due at perihelion towards the end of 1986.

For more than half a century after its first return in 1758, Halley's comet remained unique, but by 1818 three periodic comets were known, and although we should regard them as having long periods they were, in those days, considered exceptionally small; these comets were P/Halley, Pons' comet of 1812 (now known as P/Pons-Brooks), and Olbers' comet of 1815. The orbits of these had been computed by Gauss or by his pupil Encke. Then in 1818 Pons, at Marseilles, discovered a faint comet, and Encke calculated its orbit. He found a period of $3\frac{1}{4}$ years, and showed that this comet was identical with those of Méchain (1786), Caroline Herschel (1795), and Pons (1805), and, after six weeks of intensive work, he predicted the return of the comet in 1822.

It is difficult for us to realize the intense interest aroused by this work of Encke's; not only had he demonstrated the value of Gauss's methods, but he had shown the presence of an entirely new class of object within the solar system. This was only the second prediction of the return of a comet to be made after the lapse of nearly a century. The comet was duly recovered in 1822, and has made regular returns since then – 46 appearances at perihelion in all – and is due again in 1964.

Comets are usually named after the observers who discover them, but in exceptional cases the rule is not followed, and the comets named after Halley and Encke are examples of giving honour where honour is due. Another example is to be found in P/Crommelin, which was originally known by the cumbersome title of P/Pons-Coggia-Winnecke-Forbes. Crommelin showed that the comets of Pons (1818), Coggia and Winnecke (1873) and Forbes (1928), were identical, and that the period of 27 years tallied with the appearances of comets in 1457 and 1625. The comet was renamed in his honour in 1948.

In his younger days, Crommelin had assisted Cowell in calculating the behaviour of Halley's comet. Their prediction for 1910 was only a few days in error – a fine piece of work in a comet with so long a period. (It may be as well to point out that this comet was

a very disappointing object as seen from our latitudes. There was a very bright comet that appeared about the same time, and this is often remembered by those old enough, who like to delude themselves that they saw Halley's comet in 1910 in the western sky at sunset. The comet was seen at its best in the southern hemisphere.) In addition to making a prediction for 1910, Cowell and Crommelin also traced the past history of the comet; every appearance back to A.D. 989 was confirmed (including the famous one of 1066, which is depicted on the Bayeux Tapestry) and all but one or two of the returns as far back as 240 B.C.

The lengthy period of Halley's comet is somewhat unusual, most of the short-period comets revolving about the Sun in 6 to7 years. Of the total of 94 comets, there are 52 which have orbits with periods in the range 5·4 to 8·0 years, and this corresponds to a mean distance from the Sun of 3 to 4 astronomical units, with aphelion distances of the order 4 to 6 a.u. Since the mean distance of Jupiter from the Sun is 5·2 a.u., these comets may undergo severe perturbations by this planet, and this is merely one of the many lines of evidence which show the influence of Jupiter on cometary orbits. These comets are commonly known as the 'Jupiter family' of comets, but there is less justification for pushing the idea further and speaking of the 'Saturn family' or the 'Neptune family' of comets. The comets with periods of the order of 75 years (such as Halley) are supposed to belong to this 'Neptune family', but such comets can actually come closer to Jupiter than they do to Neptune, because of the inclinations of their orbits. It is always the attraction of Jupiter that dominates the behaviour of the periodic comets, and this at least must be allowed for in predicting the next return to perihelion.

The effect of perturbations is often misunderstood. If a comet is attracted by Jupiter, it does not move towards that planet; it remains always under the control of the Sun, and its motion is merely deflected to some extent. Now the entire nature of the orbit is controlled solely by the velocity (which includes the *direction* of motion, as well as the speed), and if the velocity is altered, then the whole orbit is changed. To illustrate this, let us consider just one

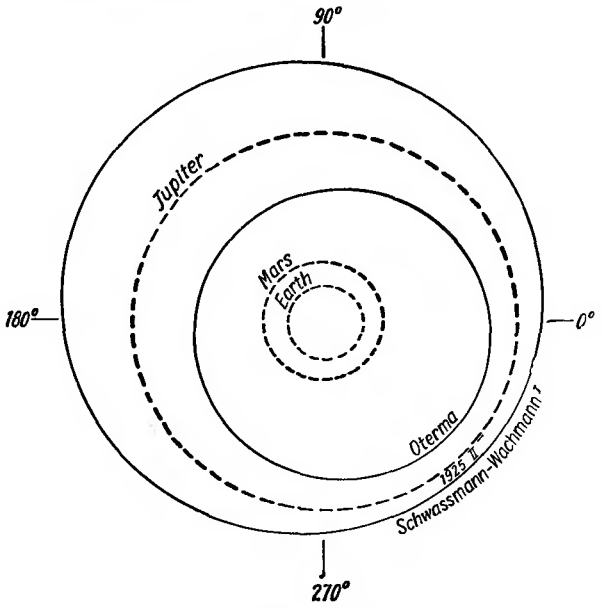
simple case – a direct attraction on the comet in the forward direction. Now, it is well known that in an elliptical orbit the speed is greatest at perihelion, and least at aphelion – thus Halley's comet is near aphelion at present, and its speed is about half a mile per second; when it comes to perihelion in 1986 it will be moving at almost 34 miles per second. It is also true that a planet in a large orbit moves more slowly than one in a smaller orbit – this follows at once from Kepler's Laws. But when we come to studying the numerous intersecting orbits of the comets we meet a curious paradox. Suppose we have two bodies – say, a comet and a planet – at the *same* distance from the Sun, then they cannot both have the same speeds, since they travel in different orbits, and, in fact, it is the body in the *larger* orbit that has the *greater* speed at any given distance. Thus a comet with a period of 6 years may go out at aphelion to the neighbourhood of Jupiter, but Jupiter's orbit is the larger, and the planet will travel faster than the comet. Nevertheless, they both travel in the same direction, and will be neighbours in space over long intervals, since the speeds are comparatively slow (about 5 miles per second for the comet, 8 miles per second for Jupiter). It is the prolonged influence of Jupiter under such conditions that causes such marked changes in cometary orbits. The attraction of the planet causes an acceleration, and this increases the velocity continuously; the increase in the speed forces the comet into a larger orbit. It may also be shown that the eccentricity is also changed by such an attraction in the forward direction (tangential to the orbit); and in the same way, forces in other directions will change the whole character of the orbit, altering its inclination or the direction of its major axis. Such effects are always present, however far away the comet may be, and they are particularly noticeable in those comets whose periods are about half that of Jupiter, because in such cases the comet may come within a short distance of Jupiter at each alternate revolution. As an example, consider P/Pons-Winnecke, which has been seen at 15 returns and whose orbit is becoming noticeably larger and less eccentric. The original orbit of 1819 had a period of 5·6 years, an inclination of 11 degrees, and a perihelion distance of

0·77 a.u. Today the orbit has a period of 6·3 years, is inclined at 22 degrees, and the perihelion distance is 1·23 a.u.

Effects of this kind can alter the orbit completely if the comet makes a really close approach to Jupiter. The word 'close' must be understood in the astronomical sense; anything less than half a unit (46 million miles) is really close. Thus Lexell's comet of 1770 had a period of 5½ years, but calculations showed that it had been very close to Jupiter to 1767 (actually within the orbits of the four big satellites). It made two revolutions about the Sun, (although only one was seen), and then again suffered severe perturbations, so that it was never seen again. The case of P/Brooks (2) is often quoted. This comet, first seen in 1889, had a period of about 7 years, but this is the result of a close approach to Jupiter in 1886, before which the period was 29 years.

We need not delve into the past to find further examples, for a very noticeable one is occurring at the present time with comet Oterma. Since 1942, when it was discovered by Miss L. Oterma, this comet has revolved about the Sun in its almost circular orbit within a period of 8 years, but it has been shown that before 1936 the period was about 18 years. At the present time it is undergoing another of these protracted disturbances by Jupiter, lasting nearly two years, and approaching Jupiter to less than a tenth of a unit; as a result its period will be lengthened to about 19 years, while its distance from the Sun will be so greatly increased that it is doubtful if it will ever be seen again.

It will be appreciated that the wide range of movement of a comet may entail a great deal of laborious calculation in making a prediction for the next return. The eccentric nature of a cometary orbit does not allow us to make many approximations, as is possible with the planets. Planetary orbits are so nearly circular that the departure from the true circle introduces only minor complications, and it is possible to express the position of the planet at any future time (allowing for all perturbations) by means of a series of equations, the numerical values of which can be arranged in a set of tables. The sums of the quantities taken from the tables will then give the position at the required date. But comets cannot be



After Richter, 'Nature of Comets'

dealt with in this way, and it is necessary to work out the effect of the disturbing planets in a step-by-step process. In this, the effect of each planet is worked out for a whole series of dates at equal intervals – perhaps 20 days. At each step the elements of the orbit will be slightly changed, and the new elements are then used for the next step. Thus if the period of the comet is 2,000 days (nearly 6 years) there will be a hundred steps at this interval, for each of which the effect of all the planets is (or should be) calculated. It is not possible to state the details of the next return until all the steps have been completed – a long and arduous task. If the perturbations are not too heavy (which would entail reducing the interval, and using more steps), it is possible to do this work on an electronic computer, but a really close approach to a major planet still remains a great difficulty. Methods of this kind are used regularly

by members of the Computing Section of the British Astronomical Association, whose predictions every year have always been of the greatest value. These predictions do not aim at the highest accuracy (for example, perturbations by Jupiter and Saturn only may be considered, the other planets being ignored), but more detailed investigations are often published, particularly by computers in the U.S.S.R., Poland and Japan. The return of Halley's comet in 1986 is the subject of a long investigation by Dr Zadunaisky, who is hoping to make use of electronic computers at the Massachusetts Institute of Technology.

However careful this kind of work may be, it does not follow that the periodic comets are seen at each return. This is often due to the fact that the comet is unfavourably placed – too near the Sun, perhaps, or too far south to be above the horizon. But it must also be admitted that predictions are sometimes not as good as they might be, for unless the prediction, and its accompanying ephemeris, are quite close to the mark, it is impossible to find the comet in a large telescope, in which the field of view is always quite small. We find ourselves in a vicious circle – no observations (or poor ones) mean that the orbit cannot be adequately corrected; a poor orbit means a poor prediction for the next return, and a poor prediction means no recovery. And so the comet becomes 'lost' – but it is the astronomer who has lost the comet, and not the comet which has vanished. Several 'lost' comets have, in fact, been recovered, some as the results of more careful calculations, others by sheer chance.

Nevertheless, comets must continuously shed their material, and this has been realized since the connexion of meteor showers with comets was established in the mid-nineteenth century. The great meteor showers of 1833 and 1866, in which the Leonids fell like snowflakes in the November sky, had already suggested the presence of an orbit for the meteoric dust, and at the end of 1866 Schiaparelli showed that the August Perseid meteors move in the same orbit as the comet of 1862. Further examples followed in rapid succession: Leverrier and Peters proved the connexion between the November Leonids and Tempel's comet of 1866,

while Weiss identified the Lyrids with the comet of 1861, and the Andromedids with Biela's comet.

The behaviour of Biela's comet did much to convince astronomers that meteors could arise from the debris of comets. This faint comet was first seen by an Austrian officer, Wilhelm von Biela, at Josephstadt in Bohemia in 1826, and almost simultaneously by Gambart at Marseilles. Both observers computed orbits, and showed that the comet was identical with the comets of 1772 and 1805. The comet was seen again at its return in 1845, but at the end of that year it was seen to split into two parts. The two comets, travelling side by side about 160,000 miles apart, had no effect on each other at all, thus proving that their masses were quite small; each part displayed a short faint tail, and the brightness of the two seemed to vary, each alternately outshining the other. In 1852, under very unfavourable conditions, the double comet was again observed, but now the two nuclei were more than a million miles apart. Both vanished, and have never been seen again. The connexion between the Andromedids and Biela's comet having been demonstrated, each successive return of the comet to perihelion was awaited with interest, but it was not until 1872 that any unusual display of meteors was noticed. On the night of November 27 in that year a really spectacular shower of meteors was seen, the shooting stars falling like a rain of fire, at the rate of several hundreds every minute. This was not, perhaps, so great a shower as those of the Leonids in 1833 and 1866, but it was impressive enough, and, to quote a writer of that period, 'it became evident that Biela's comet was shedding over us the pulverized products of its disintegration'.

It is often stated, or implied, that Biela's comet gave rise to the Andromedid shower, yet these meteors from a point near the star Gamma Andromeda had fallen in considerable numbers in the years 1741, 1798 (before the comet was discovered), as well as in 1830, 1838 and 1847. The same remark applies, with even more force, to the Leonids and Perseids, both showers having been recorded far back in history, and long before the associated comets were discovered. In more recent times, showers have been seen in

association with comets Pons-Winnecke, and Giacobini-Zinner. The latter gave notable showers in 1933 and 1946, and its meteors, which come from a radiant in Draco, have been recorded by radar methods. This shower has recently been studied from the mathematical point of view, in an attempt to decide its possible origin. Calculations on the Mercury computer at Manchester University by J. G. Davies and W. Turski have shown that the most probable source of these Draconid meteors was an eruption of material from the head of the comet in 1894, the gas and dust leaving the head with quite small velocities – certainly less than 10 metres per second.

We are still not clear as to the reason for such ejections of material from the head of a comet – they cannot possibly arise through perturbations – but if comets wear themselves out in this way, it is clear that they cannot be very ancient members of the solar system. Their origin can be guessed, for the attraction of Jupiter alone is sufficient to explain how these small orbits have been derived from larger ones by continuous perturbations by the giant planet. The question then arises as to how often the comet can return to the perihelion, constantly shedding its material, before it is finally worn out. We might make a guess that some hundreds of revolutions – some thousands of years – are needed to deplete a comet of all its gases and fine dust. Yet that is an insignificant amount of time in the astronomical sense. We need to know a great deal more about these interesting objects before we can begin to solve all the problems they present. There are already plans afoot to send a space probe out to a convenient comet to make closer measurements, or even to pass through the luminous coma which surrounds the nucleus. In a public lecture in 1958, the late Otto Struve said:

> As an astrophysicist I would like to make a satellite provided with an explosive charge blow up the solid icy nucleus of a comet. . . . It would be quite interesting to see what would happen if the entire one-mile nucleus of the comet were suddenly converted into vapour. Since the solar system contains

> approximately one hundred billion comets we need not be afraid that we shall run out of comets if we sacrifice one or several for such an experiment.

It is comforting to think that the present plans are much less drastic! The enormous difficulties are fully realized, and perhaps the greatest of these is to select a suitable comet, one which is bright enough to be observed, big enough to be worth investigating, and adequately observed over many revolutions, so that its orbit and its position in space are known with high accuracy. And there are very few comets which can be said to come up to these high standards!

Recent Advances in Astronomy

PATRICK MOORE

Each year brings its new quota of 'space research successes', and 1963 has been no exception. There was, for instance, the flight of Gordon Cooper, the U.S. astronaut, which was carried through without the slightest hitch, and which showed that the Americans have made remarkable progress since the days when they were hard pressed to launch even a small unmanned satellite. From Russia came two more spectacular *Vostoks*, one piloted by Valery Bykovsky and the other by the first woman in space, Valentina Tereshkova. The Russians were in orbit at the same time, and Bykovsky stayed aloft for longer than any astronaut before him.

There has been much discussion as to why the Russians selected a woman pilot. In some quarters, the choice was even described as a 'publicity stunt'. To me, at least, this seems ungenerous, and it surely is more likely that Valentina Tereshkova was chosen simply because she happened to be the most suitable person for that particular mission. In any case, she more than justified her selection.

But though the Russians have achieved so much, they have also had their failures, and two of their latest unmanned probes have certainly not done all that had been hoped of them.

After the successful photography of the reverse side of the Moon, in 1959, it was generally thought that further Soviet lunar probes would follow. Yet for some years, they did not; it was not until 1963 April 2 that Lunik IV followed in the wake of its predecessors. According to Russian statements, it had a weight of $1\frac{1}{3}$ tons, and was crammed with complex instrumentation.

As usual, prior information was scanty, and even when Lunik IV was on its way there was no certain indication of what it was meant to do. The most reasonable answer was that the probe was intended to make a 'soft landing' on the Moon's surface – or, alternatively, to drop a package on to the Moon, so providing an automatic lunar laboratory. It also seemed that the Russians might try to transmit television pictures of the Moon from close range, as the Americans had attempted to do with the so far unsuccessful Ranger rockets.

World attention was focused on Lunik IV as it sped toward the Moon, but the outcome was in the nature of an anti-climax. There was no landing, and presumably no television pictures. The rocket simply passed by the Moon at a distance of several thousands of miles, and went off into space, just as Lunik I had done more than four years earlier. The obvious suggestion is that the Russians were unable to guide it down on to the Moon, or to effect a separation between the hypothetical 'landing package' and the probe itself. This is as much as can be said at the moment, and at the time of writing (July 1963) no further word has come from Moscow.

The case of the Soviet probe *Mars I* was different, since here the launching was carried through faultlessly – on 1962 November 1 – and the vehicle sent back information which was of great value. Measures of cosmic radiation, for instance, were received, together with information about the so-called 'solar wind' and the magnetic fields in space. The ultimate aim of the experiment, to send the probe close to Mars and obtain new data about the Martian surface and atmosphere, was not, however, achieved. Troubles developed, and when the probe had receded to a distance of rather more than sixty million miles from Earth all contact with it was lost.

This relative failure merely serves to stress the magnitude of the American triumph with their Venus probe, *Mariner 2*. Launched in August 1962, the *Mariner* passed within 22,000 miles of Venus on December 14 of the same year. Its instrumentation functioned excellently, but when the results were analyzed

they proved to be extremely unexpected. When the *Mariner* findings were announced, early in 1963, it became clear that many of our previous ideas about Venus as a world would have to be drastically revised.

In an article entitled 'The Surface of Venus', published in the 1963 *Yearbook*, I described various theories about the planet. Since we can never see the surface, which is permanently hidden by the opaque atmosphere, direct information was lacking, but there were two possible pictures of Venus as a world. Either it was a fiercely hot dust-desert, with a surface temperature high enough to rule out advanced life-forms of the type we know, or else the planet was largely covered with water, in which case it might well support primitive marine organisms of the sort which flourished on Earth during the Cambrian Period. My own inclination was to prefer the marine theory, but in the article I did add that 'further research may show that the desert picture is right, after all . . . if we are to find out what the planet is really like, we must pin our faith in space research methods'.

One of the primary objectives of the *Mariner* flight was to obtain measures of the surface temperature of Venus. These and other details of the *Mariner* programme are described in the article by Howard Miles; suffice to say here that if the announced value (+800 degrees F.) is of the right order, we must assume that Venus is a world quite unsuited to live as we know it. Yet at any rate, *Mariner 2* has represented one of the major triumphs of the early days of practical space research.

Meanwhile, it seems that our first space-target following successful landings on the Moon is likely to be not Venus, but Mars; and the Red Planet itself came under study by the Americans – not by means of a rocket probe, but with instruments carried to 80,000 feet in a large balloon, *Stratoscope II*. (*Stratoscope I*, designed for solar research, had made a successful ascent some years before.) It may seem rather curious to leave rocketry and come back to that age-old flying machine, the balloon, but in fact balloons are in many ways more suitable than rockets for carrying out spectrographic work on the planets; they cannot

reach cosmic heights, but they can at least pass beyond most of the Earth's atmosphere, which for this purpose is quite good enough. The instruments are recoverable, which is a vitally important factor. In this new experiment, the main attention was focused upon the Martian atmosphere, and although the full results have not yet (July 1963) been published, it has been stated that five complete scans of the planet were made in infra-red, revealing definite traces of water-vapour. Mars, too, was badly placed through the rest of 1963, and will not return to opposition until March 1965, but at least an encouraging start has been made.

Before leaving the planets, mention should be made of an interesting if unspectacular visitor – the pygmy asteroid Betulia, which passed by the Earth on 1963 May 21 at a distance of only 14,600,000 miles. It never exceeded the ninth magnitude, so that a telescope was needed to show it, but it nevertheless attracted a certain amount of attention in astronomical circles.

Most of the asteroids move round the Sun in orbits between those of Mars and Jupiter. A few have eccentric paths which may bring them relatively close to the Earth; of this group the most celebrated is Eros, discovered by Witt in 1898, and which made an approach in 1931 which was used to make a new determination of the astronomical unit. Because an asteroid looks exactly like a star, its position may be determined very accurately by photographic methods, and its orbit may be calculated with great precision; this, in turn, leads to a measure for the astronomical unit. The work on Eros was analyzed by H. (afterwards Sir Harold) Spencer Jones, who finally announced a value for the astronomical unit of slightly over 93,000,000 miles.

This figure has now been superseded, since new methods, based upon radar, have been developed. Consequently, there was no international programme to make use of Betulia in the same way, though a great many photographs were taken and will later be analyzed. Studies of different type were carried out at the Flagstaff Observatory, in Arizona, by Elizabeth Roemer and E. J. Öpik, who wanted to see whether Betulia was a genuine asteroid or whether it was in fact a comet. There are a few asteroids, notably

Hidalgo (No. 944) whose orbits are highly eccentric, and decidedly cometary; Hidalgo itself travels almost from the path of Venus out to a distance comparable with that of remote Saturn. It had been suggested that Betulia, Hidalgo and others might, if carefully studied, show traces of comet-like tails. However, Roemer and Öpik failed to detect anything of the sort; under all conditions Betulia still appeared star-like, and it seems that we must regard these curious bodies as bona-fide members of the asteroid swarm.

So far as comets were concerned, 1963 was not expected to be an eventful year, though the usual faint periodical comets arrived upon schedule. A brighter, non-periodical comet was discovered in the spring by the Japanese astronomer Ikeya, and became clearly visible to the naked eye; but when at its best it lay well south of the celestial equator, and European and United States observers never saw it to advantage. By the law of averages, a 'great' comet is now surely overdue; the last appeared as long ago as 1910, whereas during the last century spectacular visitors appeared quite frequently. We may hope for at least one more brilliant comet before Halley's Comet comes back again in 1986.

In the field of stellar astronomy, perhaps the most interesting discovery of 1963 was announced by Dr van de Kamp and his colleagues in the United States. This concerned the faint object known as Barnard's Star, which van de Kamp and his team have found to be attended by an invisible body with a mass only $1\frac{1}{2}$ times that of Jupiter – in which case it must be a planet, and not simply a very dim star.

Barnard's Star is only six light-years away, so that it is our nearest stellar neighbour with the exception of the three components of the Alpha Centauri system. Its position (epoch 1950) is R.A. 17h 55m, dec. + 4° 33′, which places it in the constellation of Ophiuchus; it is of magnitude 9·6, so that it is a comparatively bright telescopic object. It is, of course, a feeble Red Dwarf. It has been nicknamed the 'Runaway Star' because its annual proper motion amounts to 10″·30, which is easily a record; the annual proper motion of Sirius, for instance, amounts to less than $1\frac{1}{2}$″.

Van de Kamp and his colleagues have spent many years in studying the motion of Barnard's Star, and have now found that this motion is not quite regular; there is evidence of perturbation by a much less massive body. Investigations of this sort are by no means new, and it is worth remembering that the faint companion of Sirius was predicted theoretically, by F. W. Bessel, long before Clark first saw it in 1862. Much more recently, 61 Cygni B has been found to be attended by an invisible lightweight companion, as was announced by K. Strand in 1944, and there are a few other examples.

The real importance of Van de Kamp's discovery is that the companion of Barnard's Star is of such remarkably low mass. A body equal to only $1\frac{1}{2}$ times the mass of Jupiter cannot possibly be a star, and it seems that for the first time we have positive evidence of an 'extra-solar' planet. The companion of 61 Cygni B is said to be at least 15 times as massive as Jupiter, so that we cannot be certain of its nature.

The results with Barnard's Star seem to be conclusive, but they will not easily be repeated elsewhere, since there are few stars of comparable distance and none with as rapid a proper motion. Meanwhile, our ideas as to the origin of our own Solar System are bound to be affected. The Sun's family cannot be in the nature of a cosmical freak – it would be too much of a coincidence to expect two such freaks, and probably more, in the very limited part of the Galaxy available for detailed study. Systems of planets are probably very common, and this in turn increases the probability of the widespread occurrence of life in our own and in external galaxies.

Another interesting event of 1963 was the discovery of a naked-eye nova near the brilliant Vega. It was detected by the Swedish amateur Dahlgren, using a pair of binoculars, and found independently at about the same time by L. Peltier in the United States. It lay so near the border between Lyra and Hercules that there was some discussion as to which constellation should claim it; eventually the International Astronomical Union pronounced in favour of Hercules. It reached the third magnitude, so that it

was the brightest nova for some time. Excluding Nova Argûs 1942, which was extremely difficult to see in Britain and the northern United States because of its southerly declination, only two more brilliant novae have appeared during the past thirty years, one in Hercules (1934) and the other in Lacerta (1936).

Nova Herculis 1963 proved to be of the slow type, and its fading was relatively gradual, so that it did not remain a naked-eye object for very long. It was, of course, carefully studied from observatories all over the northern hemisphere, and useful results were obtained. At the end of the summer of 1963 it was still easy to see with a moderate telescope.

One of the most unhappy events of 1963 was the sudden and quite unexpected death of a great astronomer – Otto Struve, one of the famous family whose first famous representative was F. G. W. Struve, of double star fame. Though of Russian descent, Otto Struve lived and worked in the United States. He made outstanding contributions to astronomical research, particularly in the field of astrophysics, and was also a very skilful writer of 'popular' books, one of which appeared not long before his death. He will be greatly missed by his friends and colleagues all over the world.

When we look back at 1963, we may claim that in many ways it was an important year astronomically. No doubt there will be further developments in 1964, though it may be too much to hope that we shall be treated to the spectacle of a brilliant nova, or even a great comet stretching its tail across the heavens.

Some Recommended Books

General:

Larousse Encyclopedia of Astronomy, by L. Rudaux and G. de Vaucouleurs. (Batchworth, 1959; 63*s*.)
Not an encyclopedia, but a detailed account of astronomy for beginners; 500 pages, and more than 800 diagrams and plates. Value for money.

Astronomy, by Robert H. Baker. (van Nostrand, 1959; $6.95.) A standard textbook, which has now reached its 7th edition.

Atlas of the Universe, by B. Ernst and T. E. de Vries. (Nelson, 1961; 42*s*.) A detailed and profusely illustrated encyclopaedia of astronomy.

The Young Astronomer, by E. A. Beet. (Nelson, 1962; 7*s*. 6*d*.) An outstandingly good, clear introduction to astronomy, written for school-age readers by the President of the British Astronomical Association.

Astronomy, by Fred Hoyle. (Macdonald, 1962; 63*s*.) A fine book, lavishly illustrated; concerned mainly with the development of modern astronomy through the application of the laws of physics.

Astronomy, by Patrick Moore. (Oldbourne, 1961; 35*s*.) A book telling the story of the development of astronomy; it has many coloured photographs and drawings.

The Fascinating World of Astronomy, by R. S. Richardson. (Faber & Faber, 1962; 25*s*.) A popular book in 'question and answer' form, written by an American astronomer who is as famous for his general books as for his own very considerable contributions to the science.

Measuring the Universe, by Henry Brinton. (Methuen: Outline series, 1962; 9*s*. 6*d*.) A logical, concise account.

Lectures and Essays:

The Exploration of Outer Space, by Sir Bernard Lovell. (Oxford University Press, 1962; 16*s*.) A book based on the Gregynog Lectures of October 1961; it deals with subjects ranging from radio astronomy to the possibility of life elsewhere in the universe. Non-mathematical, and so may be followed by the beginner in astronomy, though it will be of equal value to the serious worker.

Radio Astronomy:

Radio Astronomy, by F. Graham Smith. (Penguin, 1960; 7*s*. 6*d*.) An excellent account by one of the Cambridge team.

Radio Studies of the Universe, by R. D. Davies and H. P. Palmer. (Routledge & Kegan Paul, 1959; 25*s*.) Two members of the Jodrell Bank team explain their work.

Radio Astronomy for Amateurs, by F. W. Hyde. (Lutterworth, 1962; 25*s*.) F. H. Hyde uses the only full-scale amateur radio astronomy observatory in Britain, and collaborates extensively with American professional research workers. In this book he gives details of his equipment and methods. Invaluable for any amateur seriously interested in the subject.

The Solar System:

The Planet Jupiter, by B. M. Peek. (Faber & Faber, 1958; 42*s*.) The only detailed account – and an excellent one – of this great planet.

The Sun and the Amateur Astronomer, by W. M. Baxter. (Lutterworth, 1963; 25*s*. A book by a well-known amateur observer of the Sun, describing the methods used in this work and the results obtainable by the skilful amateur. Illustrated with many excellent photographs.

The Planet Mercury, by Werner Sandner. (Faber & Faber, 1963, 21*s*.) A non-technical account of what is known about Mercury, translated from the German by A. L. Helm.

Mars, by Earl C. Slipher. (Sky Publishing Corporation, Cambridge, Mass.) An elaborate book, containing a description of Mars and numbers of magnificent photographs, taken mainly at Flagstaff. The author has had many years' experience, and has probably paid more attention to Mars than any other astronomer of modern times.

The Measure of the Moon, by R. B. Baldwin. (University of Chicago Press, 1963; 97*s*.) A large, well-produced book. Much of it deals with the author's interpretation of the lunar craters as being due to meteoric impact, but there is also much general information, and extensive references. Very strongly recommended to all those who are in any way interested in the Moon.

Survey of the Moon, by Patrick Moore. (Eyre & Spottiswoode, 1963; 25*s*.) An account of modern selenography, including a map of the Moon in sixteen sections.

The Moon – a Russian View. Edited by A. V. Markov. (University of Chicago Press, 60*s*.) A valuable collection of lunar papers by distinguished Soviet astronomers.

The Sun's Family, by James Muirden. (Weidenfeld & Nicolson, 1962; 9*s*. 6*d*.) An account of the Solar System, written specifically for readers of school age, but also suitable for adult beginners in astronomy.

The Planet Saturn, by A. F. O'D. Alexander. (Faber & Faber, 1962; 63*s*.) A comprehensive account of Saturn – the first book dealing with this planet to be published for nearly a century. It is indispensable to any student of Saturn, and must remain the standard work.

The System of Minor Planets, by Günter D. Roth. (Faber & Faber, 1962; 25*s*.) Translated from the German by A. L. Helm. The only recent book to deal exclusively with the asteroids.

Space Research:

Satellites and Scientific Research, by D. King-Hele. (Routledge & Kegan Paul, 1962; 25*s*.) One of the best accounts so far of the behaviour and uses of artificial satellites.

Space Laboratories, by G. Zhdanov and I. Tindo. (Foreign Languages Publishing House, Moscow; in English, distributed by Central Books; 1962, 6*s*.) A useful account of the research carried out by satellites and space probes.

Artificial Satellites, by G. V. E. Thompson. (Weidenfeld & Nicolson, 1962; 9*s*. 6*d*.) A popular description of the present satellite programme.

Express to the Stars, by Homer E. Newell. (Hutchinson, 1962; 25*s*.) A detailed and authoritative account of the American space programme, and of the application of rocketry in general. The author is the Director of the Office of Space Sciences.

Miscellaneous

Changing Views of the Universe, by Colin A. Ronan. (Eyre & Spottiswoode, 1960; 15*s*.) A study of the historical background.

Astronomical Photography, by G. de Vaucouleurs. (Faber & Faber, 1961; 25*s*.) An historical account of the development of astronomical photography, from its earliest days up to the present time.

Physics of Interstellar Space, by S. Pikelner. (Foreign Languages Publishing House, Moscow, 1962; in English, 6*s*.) Semi-technical and highly informative.

Life in the Universe, by Francis L. Jackson and Patrick Moore. (Routledge & Kegan Paul, 1962; 18*s*.) A discussion of the

problem written jointly by a research bacteriologist and an astronomer.

Celestial Objects for Common Telescopes, by the Rev. E. W. Webb. (Dover Books.) A re-issue of Webb's classic book. Some of the plates have been replaced, but, unfortunately, no attempt has been made to bring the text up to date. Nevertheless, the book remains the best of its kind.

Astronomical Societies

The advantages of joining an astronomical society are obvious, and this is a step which should be taken by any amateur who is even moderately interested in the subject. The leading society in Britain is of course the Royal Astronomical Society (Burlington House, Piccadilly, London, W.1) which is a professional organization, though there are many Fellows who are amateurs. The leading amateur society is the British Astronomical Association: secretarial address 303 Bath Road, Hounslow West, Middlesex. Meetings are held on the last Wednesday of each month (except July, August and September) at Burlington House, at 5 p.m. The annual subscription is 45*s.*; for a member 25 years of age or less on his last birthday preceding 1 August, the subscription is 30*s.* Special sections are devoted to the Sun, Moon, Mercury and Venus, Mars, Jupiter, Saturn, comets, meteors, variable stars, and aurorae and the Zodiacal Light; there is also an Historical Section, and a section dealing with instruments and observing methods. The B.A.A., founded in 1890, has a distinguished observing record. Publications include a regular *Journal* and annual *Handbook*.

For young enthusiasts there is the Junior Astronomical Society (secretarial address, 44 Cedar Way, Basingstoke, Hampshire) which caters mainly, though not exclusively, for those of school age. Meetings in London are held quarterly at Caxton Hall, near Victoria. The journal, *Hermes*, is issued quarterly. The annual subscription is 10*s.* There are various branches which organize their own programmes: at Croydon (J. H. Lytheer, 1 Temple Avenue, Shirley, Croydon, Surrey); Leeds (D. Fry, 5 Belle Vue Terrace, Belle Vue Road, Leeds 3); Golders Green (Miss L. Morrison, 49 Booth Road, Colindale, London, N.W.9); and Glasgow (D. McDougall, 1444 Gallowgate, Parkhead Cross,

Glasgow E1). Other branches are in the process of formation. Inquiries should in the first instance be sent to the Society's Secretary, E. W. Turner.

Many towns have their own local astronomical societies. Among these are:

Name	*Secretarial Address*	*Member-ship*	*Annual Subscription*	*Meetings*	*Remarks*
Birmingham Astronomy Group	17 Hannafore Road, Edgbaston, Birmingham 16 (W. E. Marsh)	120	10*s* (5*s* for those under 21)	Monthly, Oct.–May at Midland Institute, Paradise Street, Birmingham	1
Bristol Astronomical Society	12 Lambley Road, Bristol 5 (S. J. Williams)	60	1 guinea (10*s* 6*d* for those under 16)	Monthly, Sept.–May, at Royal Fort, University of Bristol	
Chester Society of Natural Science: Dept. of Astronomy	15 Sheldon Avenue, Chester (Miss N. Thomas)	24	10*s* (6*s* for those under 21)	Grosvenor Museum, Grosvenor Street, Chester	2
Chesterfield Astronomical Society	10 George Street, Brimington, Chesterfield	80	15*s*	The Barnett Observatory	3
Crayford Astronomical Society	Manor House Centre, Crayford	20	—	Weekly at Manor House	4
Crewe Astronomical Society	465 Crewe Road, Wistaston, Crewe, Coventry	60	12*s* 6*d*	Crewe County Grammar School, Ruskin Road, Crewe	
Cumberland and Westmorland Astronomical Society	20 Fernleigh Drive, Seaton, Workington, Cumberland, (W. L. Rae)				
Astronomical Society of Edinburgh	126 West Savile Terrace, Edinburgh 9	130	20*s*	Calton Hill Observatory	5
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11	30	7*s* 6*d*	Calton Hill Observatory	6
Leeds Astronomical Society	The University, Leeds	120	10*s*	Leeds University, 2nd Wednesday of each month, October–March	
Leicester Astronomical Society	49 Bringhurst Road, Leicester (C. Shuttlewood)	60	1 guinea (10*s* for those aged 16–18; 5*s* for those under 16)	Leicester Museum and Art Gallery	7
Lincoln Astronomical Society	Oak Crescent, Cherry Willingham, Lincoln (P. Hammerton)	80	10*s* senior 5*s* junior	Lincoln Y.M.C.A.	8
Liverpool Astronomical Society	135 St Michael's Road, Great Crosby, Liverpool 23 (J. E. Abrahams)	200	12*s* 6*d* (4*s* for those under 21)	Royal Institution, Colquitt Street, Liverpool	9
Manchester University Astronomical Society	Dept. of Astronomy, The University, Manchester 13	85	3*s*	The University	10

Name	*Secretarial Address*	*Member-ship*	*Annual Subscrip-tion*	*Meetings*	*Re-marks*
Manchester Astronomical Society	Craigside, facing Craig Avenue, Summerseat, Bury	150	£1 (seniors) 10*s* (juniors)	Godlee Observatory Manchester College of Technology, Sackville Street, Manchester, 1	11
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland	64	15*s* (students 7*s* 6*d*)	King's College, Newcastle	
Nottingham Astronomical Society	61 Abbey Road, Beeston, Notts (Miss M. Mott)	30	1 guinea	Nottingham Mechanics Institute; first Thursday in each month	12
Norwich Astronomical Society	68 Clarendon Road, Norwich (W. E. Bennett)	60	15*s* (7*s* 6*d* for those under 17)	Assembly House, Norwich, and the Observatory	13
Swansea Astronomical Society	77 Graiglwyd Road, Cockett, Swansea (R. E. Roberts)	25	1 guinea	Royal Institution of South Wales, Swansea	14
Torbay Astronomical Society	Bluehaze, Clennon Park, Paignton, Devon (Mrs A. Longman)	30	15*s*	R.A.F. Training Centre Newton Abbot, Devon; third Thursday of each month	
Warwickshire Astronomical Society	9 Tallants Road, Bell Green, Coventry (A. Hancocks)	25	£4 (£2 for those age 17–21)	20 Humber Road, Stoke, Coventry	15
York Astronomical Society	27 Garden Flat Lane, Dunnington, York	30	£1 (students 5*s*)	York Educational Settlement	16
Preston and District Astronomical Society	Ormonde, 51 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	30	15*s* (juniors 5*s*)	Chamber of Commerce, 49a Fishergate, Preston 3rd Monday of each month, Sept.–May inclusive, 19.30 h.	17
Hull and East Riding Astronomical Society	Rosedene. Flinton, Sproatley, nr Hull	40	10*s* (School pupils 5*s*)	Kingston High School, Hull	18
Wolverhampton Astronomical Society	61 Bushbury Lane, Wolverhampton (M. Astley)	61	15*s* (5*s* to ladies and those under 18)	Committee Room, 38 Tettenhall Road, Wolverhampton 7.40 pm, alternate Mondays, Sept.–April	19

Remarks

1. The Group has a 12 in. reflector in an observatory at Birmingham, and a 21 in. is under construction. General meetings are held once a month from October to May, with lectures and film shows. The Construction Section meets weekly throughout the year. The Group runs a lending library, an observing section, and a junior section.

2. From January to May a course of lectures is held in conjunction with the Liverpool University extra-mural department, on subjects allied to astronomy. Open to non-members of the Society. Fee 7*s.* 6*d.*

3. The Observatory has an 18 in. Newtonian reflector and also a lecture room.

4. Members who have satisfied the Committee as to their competence may use the 12 in. reflector in the H. P. Wilkins Memorial Observatory.

5. Facilities are available to members at the Observatory, Calton Hill. Small telescopes are also loaned to members of the Observing Sections. Members meet on Fridays throughout the year at the Observatory. Library, and a collection of lantern slides. Monthly star maps and astronomy notes are issued to all members.

6. There are observing nights at the Observatory, Calton Hill. Monthly notes are issued to members. Some small telescopes are loaned to members. Training is given in observing techniques. There is a small library.

7. The Observatory, with a 15 in. reflector, will be completed in 1962.

8. An observatory and lecture room are now being built.

9. The Society, founded in 1881, has a strong junior section, a radio physics section, a library and a collection of lantern slides. Telescopes are available for borrowing by members, and the Society's 5 in. Cooke equatorial is available to members at a weekly meeting held at the Society's Observatory, Central Technical College, Byrom Street, Liverpool.

10. The Society has the use of the Godlee Observatory, operated by the Manchester Astronomical Society. The Society also has facilities for producing telescope objectives, etc.

11. The Society's 12 in. and 8 in. reflectors are available two nights per week at least. Winter session lectures are held in the Reynolds Hall of the College.

12. The 8·5 in. Society reflector is kept by the Director of Observing, A. W. Lane Hall.

13. The Society has its own observatory, with a 10 in. reflector,

and adjoining club-room, off Newmarket Road, Norwich. This is available to members at any time by arrangement. Regular evenings are Tuesdays, Wednesdays, and Saturdays.

14. The Swansea Observatory has a 9 in. Newtonian reflector, and photographic equipment.

15. Workshops contain grinding and polishing facilities. The Library and Club Room, available seven days a week, are available to all members. There is a monthly magazine, *Cosmos*.

16. Meetings are held at 7.30 on the second Thursday of each month.

17. The observational work of the Society is carried out at the Jeremiah Horrocks Observatory, Moor Park, Preston, on Monday evenings.

18. The observatory at Kingston High School, Hull – equipped with a 4-inch refractor – is available for use by arrangement. Meetings are held in the second Friday of each month from October to April inclusive.

19. Library facilities are available.

This list of societies may not be complete. The secretaries of any societies not included are invited to send details to Patrick Moore, c/o Eyre & Spottiswoode Ltd., 22 Henrietta Street, London WC2, for inclusion in the 1965 *Yearbook;* any alterations of details given for societies listed here should also be sent, so that the list may be kept fully up to date.

Glossary of Astronomical Terms

aberration—(1) the distortion of an image in an imperfect optical system; (2) the apparent displacement of a star from its true position owing to the finite velocity of light. It includes (*a*) the effect of light-time, the object being seen where it was when light left it; this effect is ignored in dealing with stars, since the light-time is not known; (*b*) the effect of the Earth's motion, which, combined with the velocity of light, causes an apparent displacement of the object. This effect is called *stellar aberration*, and the combination of the two effects is *planetary aberration*.

absorption lines—dark lines in a continuous spectrum caused by absorption of light of certain wave-lengths by a layer of gas (e.g., an atmosphere) cooler than the source of light.

albedo—('whiteness')—the ratio of the amount of sunlight reflected from a planet or satellite to the amount received. The Moon reflects only 7 per cent of the sunlight falling on it; its albedo is therefore 0.07.

altitude—the angular distance of a body above the true horizon; the nature of the visible horizon will affect the apparent altitude.

angstrom unit—the unit of wave-length in measurements of light, X-rays, etc. Symbol A; it is one hundred-millionth part of a centimetre, or a ten-thousandth part of a micron. The whole of visible light is contained in the range from 3,900A (violet) to 7,500 A (red).

aphelion—that point in an (elliptical) orbit of a planet or comet which is farthest from the Sun.

apogee—that point in the orbit of the Moon, or of an artificial satellite, which is farthest from the centre of the Earth.

apparent place—the observed position of a star or planet, as distinct from the mean place.

apparent solar time—time measured by the hour angle of the true Sun; the time measured by a sundial. The difference apparent time *minus* mean time is the *equation of time*, and this may amount to more than 16 minutes in November.

appulse—a very close conjunction of two planets, or of a planet and a star.

apse line, or *line of apsides*—the line in an orbit which joins the nearest and farthest points from the central body; in an unperturbed ellipse it corresponds to the major axis.

asteroids—see *minor planets*.

Astronomical Ephemeris—the modern name (since 1960) of the British *Nautical Almanac*, which was first published in 1767; it is identical in content with the *American Ephemeris*.

astronomical unit—the mean distance of the Earth from the Sun; the semi-major axis of the Earth's orbit. May be taken as 93 million miles.

astrophysics—the branch of astronomy which uses the laws of physics to study the constitution and evolution of the stars.

az muth—the angular bearing of an object measured round the horizon from north or south points. In astronomy it is now usual to measure the azimuth from the north round through east, south and west, from 0° to 360°.

binary—a double star in which the two components are physically connected, revolving about their common centre of mass under the influence of the mutual gravitational forces. Probably one star in every two or three is a binary.

celestial sphere—an imaginary sphere of infinite radius, centred at the observer, on which the stars and planets appear to be fixed.

Their positions may then be referred to fixed great circles (such as the equator or ecliptic) on the sphere.

cepheid—a variable star characterized by a rapid rise to maximum brightness, followed by a slower and less regular decline; named after the typical star Delta Cephei. The periods range from 1 to 45 days, and the period is in all cases proportional to the absolute brightness, from which distances can be measured.

chromosphere—the lower layer of the Sun's atmosphere, red in colour, and consisting mainly of hydrogen; it extends for some thousands of miles, while prominences rise from it to much greater distances.

circumpolar stars—stars which do not rise or set, but merely circle the pole; all stars whose declinations are greater than the colatitude of the observer are circumpolar.

cluster variables—short period variable stars first detected in globular clusters, and having periods less than one day.

clusters—groups of stars having a common motion through space. The main groups are (1) open clusters within the Galaxy containing at most a few hundred stars with dust and gas clouds; (2) globular clusters of a symmetrical shape, containing many thousands of stars including short-period variables and Population II stars. They are distributed uniformly at great distances round the centre of the Galaxy.

colatitude—the complement of the latitude; 90° minus the latitude. The meridian altitude of the equator at any place is equal to the colatitude.

colour index—the difference between the photographic and visual magnitudes of a star; from this value the effective temperature may be deduced.

comes—the fainter component of a double star.

conjunction—the nearest apparent approach of two celestial objects, when one appears to pass the other; usually considered to occur when they have the same longitude.

Inferior conjunction of Mercury and Venus occurs when the planet is between the Sun and the Earth.

Superior conjunction of any planet occurs when it is on the farther side of its orbit, the Sun lying between planet and Earth.

continuous creation—the theory that matter is being continuously created throughout the universe, to replace losses caused by the recession of the galaxies. This is the *steady-state* theory, and it implies that the universe had no beginning and will have no end; creation is confined to individual systems.

corona (*solar*)—a pearly-white halo of light surrounding the Sun; this is the outer layer of the Sun's atmosphere, and can be traced to great distances from the Sun, joining up with the zodiacal light.

cosmic radiation—highly penetrating radiation which reaches the Earth from outer space; it consists of electrically charged particles of high energy.

cosmogony—the science which deals with the origin of the universe, or of our Galaxy or the solar system.

cosmology—the study of the universe as a whole, its nature in space and time, and the relations between its various parts.

cusps—the horns of the moon or of an inferior planet when in the crescent phase.

D-layer—the lowest ionized layer in the Earth's atmosphere; it is about 50–60 miles above the Earth, and disappears almost completely at night.

day—the period of the Earth's rotation. It may be measured with respect to the stars (*sidereal day*), the true sun (*apparent solar day*) or the mean sun (*mean solar day*). See *apparent solar time*, *Greenwich Mean Time*, *mean solar time*, *sidereal day*.

declination—the angular distance of a celestial object north (+) or south (−) of the celestial equator.

dew cap—an open tube fitted to a refractor, extending the telescope tube beyond the objective; it prevents condensation on the front surface of the lens.

diffraction rings—the image of a star in a telescope is not a point, but has a definite size; this 'spurious disc' is surrounded by a number of diffraction rings. These are caused by the spreading of light (which is a wave-motion) round the edges of an obstacle —in this case, the aperture of the telescope—to give alternate light and dark bands called diffraction fringes. If the aperture of the telescope is increased, the spurious disc becomes smaller, and the diffraction rings less conspicuous.

Doppler effect—the apparent change of wave-length in any form of wave-motion (sound, light, radio, etc.) caused by the motion of the observer or of the source, or both. The change is proportional to the velocity.

double stars—two stars which appear close together in the sky, either because they are physically connected (see *binary*) or because they chance to be almost in line, though at different distances (optical double).

dwarf stars—the stars of the *main sequence*; the giant stars are more luminous, and the white dwarfs less luminous, than the stars of the main sequence.

eclipse—an eclipse of the Moon (or any other satellite) occurs when it passes into the shadow of the planet; such an eclipse may be *penumbral* if the satellite does not enter the umbra of the shadow, or *partial* or *total*. An eclipse of the Sun occurs when the Moon passes between the observer and the Sun; in this case the eclipse may be *partial*, *annular* (ring-like, if the Moon does not entirely cover the Sun's surface) or *total*. An eclipse of the Sun can only occur at New Moon, and an eclipse of the Moon only at Full Moon.

ecliptic—the great circle on the celestial sphere which marks the apparent path of the Sun. It is the projection of the Earth's orbit on the celestial sphere.

elongation—the apparent angular distance of a planet from the Sun, or of a satellite from the parent planet, etc.

emission lines—bright lines in a spectrum due to the emission of light from a glowing gas at low pressure.

ephemeris—a table of positions of the Sun, Moon, planets, comets, etc., for given dates at regular intervals.

epoch—a date chosen for reference purposes in quoting astronomical data which vary with time, e.g., the position of the equinox, or the elements of an orbit, are always quoted for a certain epoch.

equator—the celestial equator is the great circle on the celestial sphere which is the projection of the terrestial equator.

equatorial—a telescope arranged to rotate about an axis parallel to the Earth's axis, so that as it turns it will keep a star constantly in the field of view as it moves from east to west across the sky.

equinox—one of the points of intersection of the equator and ecliptic; also the times at which the Sun passes through these points, the vernal equinox occurring on 20 or 21 March, the autumnal equinox on 23 September. The vernal equinox or First Point of Aries is the origin from which right ascension and longitude are measured.

escape velocity—the least velocity which an object must acquire, at a given distance from a centre of attraction (e.g., Sun or planet), in order to escape from the gravitational field of the attracting body in a parabolic orbit. This parabolic velocity depends on the distance, and is 1·414 times the velocity in a circular orbit at that distance.

evening star—(1) the planets Mercury or Venus when seen in the western sky at sunset; (2) also used more loosely to describe any planet which (after opposition) transits before midnight.

expansion of the universe—the recession of the extra-galactic nebulae, at rates which are proportional to their distances, is taken as evidence that the universe is continuously expanding. See *red shift*, *Hubble's constant*.

extra-galactic nebulae—the nebulae that lie outside our Galaxy; they are themselves galaxies, and tend to form clusters.

First Point of Aries—see *equinox*.

flares (*solar*)—brief but very bright outbursts of hydrogen, seen on the Sun, usually in the neighbourhood of sunspots; often cause radio fade-outs and magnetic disturbances on Earth.

flare stars—stars whose spectra show outbursts of light of a similar nature to solar flares, but on a much greater scale.

free fall—the normal state of motion in an orbit in space under the gravitational attraction of a central body. In free fall, the vehicle is not driven, and everything within it is in a state of zero gravity.

frequency—the number of waves passing a given point every second. The product of frequency and wave length gives the velocity of the waves.

galaxies—the name now used for the extra-galactic nebulae; it is estimated that 10,000 million galaxies are observable.

Galaxy—(1) the Milky Way; (2) the entire system of gas, dust and stars, of which the Sun is one; it is now known to have a spiral structure.

gauss—the unit in which the intensity of a magnetic field is measured. The Earth's magnetic field varies over the surface from about 0·3 to 0·6 gauss.

gegenschein—a faint glow in the sky sometime seen on the ecliptic opposite the Sun. It appears to be connected with the zodiacal light, and is sometimes called the counterglow.

Geiger counter—a gas-filled tube which permits an electric charge to pass through it when the gas is ionized; used for counting the number of charged particles that enter it.

geocentric—having the centre of the Earth as origin or as viewpoint.

giant stars—stars which are more luminous (and therefore have a greater surface and size) than the main sequence stars of the same spectral type.

great circle—a circle on the celestial sphere which divides the sphere into two equal hemispheres, e.g., the horizon, the

equator, the ecliptic. The shortest distance between two points on the celestial sphere is an arc of a great circle.

Greenwich Mean Time (G.M.T.)—mean solar time, measured from the meridian of Greenwich and reckoned through 24 hours from Greenwich midnight; it is identical with Universal Time.

Hα (hydrogen alpha)—one of the lines of the hydrogen spectrum; it is prominent in the spectrum of the Sun (at 6563 A) and gives the red colour to the chromosphere and prominences.

harvest moon—in the northern hemisphere the Full Moon which occurs nearest to the autumnal equinox, when the Moon rises on successive nights at about the same time. The same phenomenon occurs in March–April in the southern hemisphere.

heliocentric—having the Sun as origin; viewed from the centre of the Sun.

horizon—the great circle on the celestial sphere which is everywhere 90° from the zenith; the observed horizon will differ from this because of obstructions or the height of the observer.

hour angle—the angular distance of a celestial body from the meridian, measured along the equator westwards in hours, minutes and seconds; it is found by subtracting the right ascension of the body from the local sidereal time.

Hubble's constant—the factor of proportionality in Hubble's Law connecting the velocity of recession of the galaxies with their distance. Recent work suggests a value of 55 km/sec per million light-years, and this leads to a figure of about 6,000 million years since the recession began, i.e., when the galaxies were almost in contact. See *expansion of the universe*.

Hunter's Moon—the Full Moon following the harvest moon, at which time conditions are often very similar.

hydrogen I and II—the hydrogen of interstellar space is either neutral atomic hydrogen (hydrogen I), or ionized hydrogen (hydrogen II). Hydrogen I is observable only by means of the

21 centimetre radio line; hydrogen II is found in the neighbourhood of very hot stars, and is readily photographed.

inferior planets—Mercury and Venus, which are inferior in the sense of revolving in orbits smaller than the Earth's.

inner planets—the planets Mercury to Mars; a loose term used to distinguish them from the outer planets, which lie at much greater distances from the Sun.

interferometer—an instrument for making very small measurements by utilizing interference fringes. Two rays of light travelling along different paths from the same source may reinforce or cancel each other, so producing alternate light and dark bands, the distance between which is a measure of the difference in the two paths of the light rays. The optical interferometer has been used for measuring the diameters of some supergiant stars; similar principles are used in the interferometers used in radio astronomy.

interplanetary matter—a term which may be used to include comets, meteoric dust, cosmic rays, dust, electrons, etc., and which emphasizes the fact that space is not empty.

interstellar hydrogen—the commonest element in the universe—see hydrogen I and II.

ionization—the production of electrically charged particles from a neutral atom or molecule. In astronomy the ions of the metals, and of hydrogen and other gases are of the most frequent reference; these are ionized by the loss of electrons, producing positively charged ions.

ionosphere—the upper region of the Earth's atmosphere, in which the gases are largely ionized. Several layers (F-layer, E-layer, D-layer) are recognized, and these have the property of reflecting radio-waves, so making long-distance short-wave communication possible.

island universes—an old term for the extra-galactic nebulae.

isophotes—lines which connect points of equal light intensity on a

graph or chart; the effect is to produce a kind of contour map which indicates levels of brightness.

kiloparsec—a thousand parsecs; about 3,260 light-years.

latitude—(1) on Earth, the angular distance north or south of the equator; (2) celestial latitude is the angular distance north (+) or south (−) of the ecliptic.

librations—apparent oscillations of the Moon on its axis, due to the inclination of the orbit of the Moon, and to its varying velocity. The term is also used of other forms of oscillation of planets or satellites.

light-time—the time taken by light to travel from a celestial object to the observer. This may vary from a little more than a second in the case of the Moon, to many thousands of millions of years in the case of some of the distant galaxies.

light-year—the distance that light travels in a year at a speed of 186,000 miles a second. It amounts to 5,880,000,000,000 miles or 63,240 astronomical units. The nearest known star (Proxima Centauri) is at a distance of 4·3 light years.

line of sight velocity—see *radial velocity*.

local group—a cluster comprising nearly a score of galaxies, of which our Galaxy is one; the group also includes the Andromeda nebula and the Magellanic clouds.

longitude—(1) on Earth, the angular distance east or west of the meridian of Greenwich; (2) celestial longitude is the angular distance, measured along the ecliptic from 0° to 360°, eastwards from the equinox.

luminosity—the actual output of light of a star, as opposed to the apparent brightness measured on Earth by an observer.

Lyman alpha—the first (longest wavelength) of a series of lines in the ultra-violet spectrum of hydrogen.

Lyot filter—a light filter used in viewing the Sun; it allows the passage of light of a very restricted wave-length band (usually that of Hα) and permits direct observation of the sun's chromosphere.

M = Messier. An abbreviation applied to the number of a nebula in Messier's catalogue.

Magellanic clouds—two large irregular nebulae visible to the naked eye in the southern hemisphere; these are the two nearest galaxies.

magnetic field—the entire space in which magnetic forces can be detected; apart from the Earth's magnetic fields, there are known to be strong magnetic fields associated with sunspots and certain stars, and there is believed to be a magnetic field in interstellar space.

magnetic storms—large scale disturbances in the Earth's magnetic field, associated with solar activity; usually accompanied by displays of aurorae and the disruption of radio and telegraphic communication.

magnitude—the measure of apparent brightness of a star or planet. The naked eye can appreciate stars down to magnitude 6, but the 200-inch telescope can photograph stars a little fainter than magnitude 22. A difference of one magnitude represents a ratio of brightness of 2·512; an increase of 5 magnitudes therefore indicates a hundred-fold decrease in brightness. *Absolute magnitude* is the magnitude a star would have if it were seen from a standard distance of 10 parsecs.

main sequence—if the stars are arranged in order of increasing absolute magnitude, the vast majority of them form a progressive sequence of decreasing temperature, size and brightness; this main sequence is best displayed on a graph of absolute magnitudes against spectral type, colour index or temperature. The Sun belongs to the main sequence.

mass spectrometer—an instrument for determining the masses of positively charged particles (e.g. metal ions) by measuring their displacement in a combined magnetic and electrostatic field.

mean place—the position of a star as given in a star catalogue is a mean place, referred to some particular epoch and equinox. The effects of precession, nutation, aberration and (where

appreciable) of parallax, proper motion and orbital motion have been removed; these can be re-calculated for any future date, and when added to the mean place give the apparent place for that date.

mean solar time—a uniform measure of time defined by the hour angle of the mean sun; see *G.M.T.*

mean sun—an imaginary body which moves round the celestial equator at a uniform speed equal to the average rate of motion of the true Sun round the ecliptic.

meridian—the great circle on the celestial sphere which passes through the poles and the zenith, intersecting the horizon at the north and south points. The term is generally used only of the upper meridian, i.e., that part of the meridian from the south point, up through the zenith to the pole.

meteor—a 'shooting star'; not a star, but a small particle which enters the Earth's atmosphere from outer space, and is destroyed by friction, leaving a luminous streak in the upper atmosphere; height 40 to 90 miles, speed 10 to 40 miles per second. The very bright meteors are called *fireballs*, or (if they explode) *bolides*. Most meteors are sporadic, but certain streams of meteoric dust are known, whose orbits about the Sun are intersected by the Earth each year. The resulting increase in the number of meteors, which will all come from some particular radiant, is known as a *meteor shower*. Meteors are also detected by radar methods and some daylight showers are of great interest.

meteorite—a solid body of iron or stone which falls on the Earth's surface from outer space; meteorites are thought to be of a different nature from the average meteor, and are probably derived from minor planets rather than comets.

Metonic cycle—a period of nineteen years, after which the whole cycle of phases of the Moon repeats on the same days of the year; named after the Greek astronomer Meton (*c.* 432 B.C.).

micrometeorites—fine dust of a meteoric origin, but too fine to be destroyed by friction in the atmosphere.

micron—a unit of length equal to one thousandth of a millimetre.

midnight sun—a popular term for the appearance of the Sun above the horizon all night in high latitudes; the phenomenon is visible at some period of the year from all places within the Arctic or Antarctic circles. The Moon and planets can, of course, display the same phenomenon.

Milky Way—the band of light extending round the sky, which is shown by the telescope to consist of countless faint stars; it represents our view of the Galaxy in which we are immersed.

minor planets—a swarm of small bodies, less than 500 miles in diameter, most of which revolve about the Sun between the orbits of Mars and Jupiter. About 1,600 have well-defined orbits, but their total number probably runs into hundreds of thousands. Also called *asteroids*.

month—the average period of revolution of the Moon about the Earth; it bears no relation to the calendar month. The length of the month depends on the point of reference; the more important are the *sidereal month*, referred to the stars, of 27·32 days, and the *synodical month*, referred to the Sun, and giving 29·53 days between similar phases. Owing to the variations in the Moon's orbit, the actual length of the month may vary considerably.

morning star—Mercury or Venus, when seen in the eastern sky before dawn. Also used as a loose description of any planet which transits after midnight (i.e., before opposition).

Nautical Almanac—the navigational ephemeris, giving astronomical information in a form suitable for use by navigators.

nebulae—originally the term referred to any hazy patch of light among the stars; it is now restricted to the gaseous nebulae (either bright or dark) which are found in or near the Milky Way, and are irregular in outline. The extra-galactic nebulae, more regular in shape, show the spectrum of starlight, and are galaxies (spiral, elliptical, etc.); they are found in all parts of the sky.

neutrons—the neutral particles which, together with protons, form the nuclei of atoms.

node—the points at which the orbit of a planet, comet, satellite, etc., intersects the plane of the ecliptic (or other great circle of reference).

nova—a star which appears suddenly in the sky. Sometimes called 'new' or 'temporary' stars, but the appearance is due to an intense outburst of light from the surface of an unstable star. A score or more appear every year in our Galaxy. See also *supernova.*

nucleus—the massive part of an atom, composed of protons and neutrons. The term is also applied to the denser parts of the head of a comet or other luminous object.

nutation—a nodding of the Earth's axis; a small irregular oscillation of the pole about its mean position, and therefore additional to the slow uniform motion of precession.

obliquity of the ecliptic—the angle between the equator and the ecliptic; may be regarded as the angle at which the Earth's axis is tilted.

occultation—the disappearance of a star (or other body) by the passage in front of it of a nearer body of larger apparent size. The most important occultations are those of stars, planets, and radio sources by the Moon.

opposition—a superior planet is at opposition when its longitude differs from that of the Sun by 180°.

outer planets—a term used for the planets Jupiter to Pluto.

parabolic velocity—see *escape velocity.*

parallax—the apparent change in the position of an object on the celestial sphere caused by a change in position of the observer. *Annual parallax* is the change in position of a star due to the annual motion of the Earth, and is the angle subtended by the radius of the Earth's orbit; generally called simply parallax. *Horizontal parallax* of the Moon or of a planet is the angle subtended at that body by the Earth's equatorial radius.

parsec—the distance at which the (annual) parallax of a star is 1 second of arc. It is a large unit, equal to 206,265 astronomical units, or 3·26 light-years.

penumbra—the outer diffuse region of the shadow of the Moon or of a planet, where some light is still received from the Sun; the term is also applied to the outer regions of a sunspot.

perigee—that point in the orbit of the Moon, or of an artificial satellite, which is nearest to the centre of the Earth.

perihelion—that point in an orbit in the solar system which is nearest to the Sun.

perturbations—disturbances in the regular orbital motion of a planet, comet, etc., caused by the gravitational attraction of other bodies.

phases—the changing shape of the illuminated part of the Moon (or of a planet or satellite) due to the relative positions of Sun, Moon and Earth. The Moon and the inferior planets show all the phases from *new* (when the body is invisible) through *crescent, quarter, gibbous* to *full,* decreasing through *gibbous, quarter* to *crescent* and *new* again. The superior planets and their satellites show only the full and gibbous phases.

photoelectric cell—an electronic device in which the incidence of light causes a change in an electric current.

photoelectric photometry—an important branch of modern photometry in which the photoelectric cell is used to measure stellar magnitudes, etc.

photographic zenith tube (P.Z.T.)—a fixed telescope directed to the zenith, used for photographing stars as they pass overhead for the exact determination of time.

photometry—the measurement of the apparent brightness of a distant source, such as a star, by comparison with that of a source of known intensity.

photomultiplier—a complex form of photoelectric cell, giving enormous amplification of the initial current.

photon—the smallest amount (or 'quantum') of light energy. It

may be thought of as a particle whose mass depends on the frequency, or as a short train of waves.

plage—bright hydrogen or calcium clouds that are observed near sunspots in the Sun's chromosphere; originally called 'bright flocculi'.

planet—a large, cold, solid body, moving in an elliptical orbit about the Sun, and shining solely by reflected sunlight. In addition to the nine major planets, many hundreds of minor planets are regularly observed.

polarization—the process by which light or radio waves are restricted to vibrations in one direction (or plane) only.

pole—the celestial poles are the points on the celestial sphere towards which the axis of the Earth is directed. The word is also used with reference to any great circle; the diameter of the sphere which is perpendicular to the great circle will intersect the sphere at two points called poles.

Populations I and II—a term used by Baade to distinguish two main types of stars. Population I contains the hot blue-white stars found in the arms of spiral galaxies; Population II stars are the older red stars found in the central regions of galaxies and in globular clusters, where dust and gas are absent.

position angle—the direction of one object from another; measured from the north point of the principal object through east from 0° to 360°.

precession—the slow twisting of the Earth's axis in space, the pole describing a circle round the pole of the ecliptic in a period of about 26,000 years. This does not alter the relative positions of the stars, but causes the equinox to move westwards round the ecliptic, so that the positions of the stars with respect to the equator (i.e., the R.A. and dec.) or the horizon change slowly with time.

primary focus—(prime focus)—the focal plane of the objective or main mirror of a telescope; the term indicates that the instrument is used without an eyepiece or any other lens or mirror.

profile, line—a tracing of the intensity of the image of an emission line; measured across the line it reveals the fine structure in detail.

proper motion—the motion of a star at right angles to the line of sight; the actual change of position of the star due to its real motion in space.

proton—the positively charged particle which forms the nucleus of the hydrogen atom. The nuclei of other atoms are composed of protons and neutrons.

pulsating stars—variable stars, both irregular and of the cepheid type. Such stars are believed to expand and contract, and are brightest when contracted. The behaviour is not, however, completely understood.

quadrature—the positions of two celestial bodies when their directions from the observer are at right angles; generally used of the Moon or a planet when at an elongation from the Sun of 90° or 270°.

radial velocity—the velocity of a star towards, or away from, the observer; measured by the Doppler effect in the star's spectrum.

radiant—the point (or small area) from which the tracks of the meteors in a meteor shower appear to originate. This is an effect of perspective (as in the case of railway lines), the paths of all the meteors in the shower being sensibly parallel.

radio astronomy—the study of radio waves received from the Sun, planets, interstellar hydrogen, and more distant galactic sources; also the use of radar methods in studying the Moon, planets, meteors, etc.

radius vector—the line joining any body revolving in an orbit to its centre of attraction, as the line joining a planet to the Sun.

red shift—the extra-galactic nebulae show a displacement of their spectral lines towards the red end of the spectrum. This is interpreted as a Doppler effect, indicating that all these galaxies are receding from us. See *expansion of the universe.*

reflector—a reflecting telescope, in which the initial image is formed by reflection from the upper surface of a spherical or parabolic mirror.

refractor—a refracting telescope, in which the image is formed by refraction through the main lens, called the object glass or objective.

refraction—the bending of a ray of light when it passes from one transparent medium to another.

resolving power—the ability of an optical instrument to show fine detail or to separate the images of very close objects; resolving power depends on the aperture of the instrument.

retrograde motion—(1) the apparent westerly motion of a planet among the stars caused by the easterly motion of the Earth; with a superior planet, opposition occurs about the mid-point of the retrogression. With the inferior planets, retrograde motion occurs at the time of inferior conjunction, and is not so readily observed. (2) True retrograde motion occurs in the orbits of comets and satellites which have inclinations greater than 90°.

revolution—orbital motion about a centre of attraction, as in the revolution of the Earth about the Sun.

right ascension—the angular distance of a body from the equinox, measured eastwards along the celestial equator, and usually expressed in hours, minutes and seconds up to 24 hours.

rotation—the turning of a body about its axis; thus the Earth rotates about its axis, but revolves about the Sun.

Saros—the eclipse cycle of 6,585·3 days (18 years and 10 or 11 days) after which Sun and Moon return to the same relative positions with respect to the Moon's node, and the entire series of eclipses repeat in the same order and under similar conditions. During one Saros there are about 70 eclipses, 41 of the Sun and 29 of the Moon.

Schmidt telescope—a reflector in which the surface of the main mirror is part of a sphere, and the resulting aberrations are

corrected by a thin glass correcting plate placed before the mirror.

semidiurnal arc—the angle (or the time) required by a celestial object to describe its apparent motion across the sky from rising to transit, or from transit to setting.

sidereal day—the interval between two successive transits of the same star; it is equal to $23^h\ 56^m\ 04^s{\cdot}09$ of mean solar time, and the difference from 24 hours causes the stars to rise and set 4 minutes earlier each day.

sidereal period—the period of a planet or comet measured with respect to the stars.

sidereal time—time measured by rotation of the Earth with respect to the stars. The sidereal time at any place is equal to the right ascension of an object on the meridian at that time.

solar motion—the motion of the Sun (with reference to the neighbouring stars) of about 12 miles per second towards the constellation Hercules; the term is also used of the Sun's share in the rotation of the Galaxy, which carries it towards the stars of Cygnus at about 130 miles per second.

Solar System—the Sun, with its family of planets, comets, meteors, satellites, dust and gas, all of which are controlled by the Sun's gravitational attraction and are influenced by its radiation.

solar parallax—the horizontal parallax of the Sun; it amounts to $8''{\cdot}79$, from which is derived the distance of the Earth from the Sun.

solstice—the place (or the time) at which the Sun reaches its greatest declination north (summer solstice) or south (winter solstice).

spectral types—the main types of stellar spectra, arranged in order of decreasing temperatures, are denoted by the letters O-B-A-F-G-K-M-R-N-S, each group being further subdivided by the use of small letters or of figures from 0 to 9. There is thus a progression from the hot blue-white helium stars, through the

hydrogen stars of type A to the stars of type G, like the Sun, in which numerous metallic lines are seen; the stars of later types become cooler and redder, and show absorption bands due to molecules such as titanium oxide and carbon compounds.

spectrograph—an instrument for photographing spectra.

spectroheliograph—an instrument for photographing the Sun in the light of one particular wave-length, giving, for example, the appearance of the hydrogen or calcium clouds of the chromosphere.

spectrohelioscope—an instrument for continuously viewing the Sun in the light of one wave-length.

spectroscopic binaries—binary stars which are so close together as to be invisible in the telescope, but which are so placed that their double spectra can be studied by means of the Doppler effect.

spectrum—the rainbow band of colours produced when white light from a small source is passed through a glass prism is really a series of overlapping images of the source, each different colour corresponding to a definite wave-length. Only an incandescent substance produces this continuous spectrum; a single element in the gaseous state produces a line spectrum, i.e., only certain wave-lengths are present, as coloured lines. The positions of these lines serve to identify the element. See also *emission lines*, *absorption lines*, *Doppler effect*.

star—a self-luminous globe of gas of the same general nature as the Sun, although it may differ in size and temperature, etc. There are probably a hundred thousand million stars in our Galaxy.

stationary point—a point in the apparent path of a planet at which it appears to be stationary in longitude (but may still be moving in latitude). Stationary points occur at the beginning and end of the period of retrograde motion, i.e., before and after opposition or inferior conjunction.

steady-state theory—see *continuous creation.*

Sun—a star of spectral type G and absolute magnitude +5. It is a sphere of intensely hot gas, about 864,000 miles in diameter; the surface temperature is about 6,000°C but must rise to many millions of degrees in the interior. The visible surface is the *photosphere*, above which lie the *chromosphere* and the *corona.* The Sun rotates, in the same direction as the planets revolve, in about 25 days.

sunspot—a dark spot appearing on the Sun; the dark centre (the *umbra*) is surrounded by the lighter *penumbra*, but they only appear dark by contrast with the brilliant solar surface. A sunspot may be as much as 100,000 miles or more across.

sunspot cycle—the number of sunspots shows a marked tendency to maximum about every eleven years; there are considerable variations both in the numbers and the period.

supergiant stars—intensely luminous stars of low density and great size; their constitution and evolution appear to be different from that of ordinary stars.

superior planets—the planets from Mars to Pluto, which revolve in orbits larger than that of the Earth.

supernova—an exceptionally brilliant nova, rare in our Galaxy, but so brilliant that about 50 have been observed in other galaxies. The Crab nebula is the remains of a supernova explosion.

synchrotron—a machine for accelerating charged particles in a combined electrostatic and magnetic field. At very high energies, an electron beam produced in this way gives out a blue glow which is called synchrotron radiation.

synodic period—the time taken by a planet or satellite to return to the same relative positions with respect to the Sun and Earth; hence the average interval between oppositions or conjunctions.

terminator—the line separating the dark and illuminated sides of a planet or satellite. The terminator on the Moon is quite

sharp, indicating the absence of any appreciable atmosphere; the Sun is rising on the terminator before Full Moon, and is setting on this line afterwards.

transit—the passage of any celestial body across the meridian; also used for the passage of a satellite or its shadow across the face of a planet, or of Mercury or Venus across the face of the Sun.

twilight—the illumination of earth and sky which lasts from sunset until darkness, and from darkness until sunrise; there would be no twilight in the absence of an atmosphere, as on the Moon. Theoretically, darkness begins and ends when the Sun is 18° below the horizon, but in this country in the summer months the Sun is not depressed to this extent, and there is a certain amount of twilight throughout the night.

umbra—the central dark part of the shadow of the Moon or of a planet, where no light is received from the Sun; also applied to the darker central region of a sunspot.

U.T.—universal time—see *G.M.T.*

variable stars—stars whose light varies because of some internal cause; the eclipsing binaries are also variable, but are generally treated as a separate class. *See cepheids, cluster-type variables, nova.*

wavelength—the distance between successive troughs or crests in a wave motion; the velocity of the wave is given by frequency multiplied by wavelength. See *angstrom unit.*

W-type stars—see Wolf-Rayet stars.

white dwarfs—very small faint stars of extraordinarily high density; the normal structure of the atoms in these stars has broken down, and they contain nuclei and electrons packed together as tightly as possible. Their masses are about the same as that of the Sun, but the density may rise to millions of times that of water. Such stars appear to be very common, but are faint and difficult to detect. The best known example is the companion of *Sirius.*

Wolf-Rayet stars—a small group of stars of very high temperature, whose spectra (type W) show broad bright emission lines. It is believed that the stars are surrounded by expanding shells of gas.

year—the period of the Earth's revolution about the Sun. Measured from equinox to equinox it amounts to 365·2422 days, and the civil calendar, with its rules for leap-years, is designed to allow for the extra decimal of a day.

Zeeman effect—the splitting of a spectrum line into a number of components when the source of light is subject to a strong magnetic field; it is observed in the spectra of sunspots.

zenith—the point on the celestial sphere which is directly overhead, as determined by a plumb-line.

zodiac—a belt of the sky about 8° wide on either side of the ecliptic, in which the Sun, Moon and major planets are always to be found.

zodiacal light—a faint luminous band of light along the ecliptic stretching outwards from the Sun; best seen after sunset or before sunrise. Its spectrum is that of reflected sunlight, and it appears to consist of small particles, forming an extension of the solar corona.

Some Interesting Telescopic Objects

The owner of a small telescope must not expect too much from his instrument. Those wonderful photographs of nebulæ which are used to illustrate text-books are taken with long exposures with large telescopes, and the photographic process can reveal far more than the eye can ever see. However, there is plenty to look for in the sky, and any instrument, however small, will show a great deal of the wonder and beauty of the universe around us.

A telescope is seldom satisfactory for the study of large clusters and groups of stars because the field of view is too small. A pair of binoculars is easier to handle, and will give magnificent views of open clusters such as the Pleiades, the colours of some of the more brilliant stars such as *Betelgeuse* and *Antares*, and the fascinating chains and lines of stars in many parts of the Milky Way, especially in Aquila, Cassiopeia, Cygnus, Lyra and Perseus.

In the following list, which makes no pretence of being complete, some of the more interesting telescopic objects are arranged in order of right ascension. They may all be found on a suitable star atlas, such as *Norton's Star Atlas* (Gall & Inglis), and positions have been given for the benefit of those observers who have telescopes equipped with setting circles.

ALPHA CASSIOPEIÆ (*Shedir*). R.A. $0^h\ 38^m{\cdot}5$, Dec. $+56°\ 20'$

A K-type star in the W. of Cassiopeia. It is an irregular variable, fluctuating between magnitude 2·1 and 2·7, though its normal magnitude is about 2·3. Generally speaking, the variations are very slow, and there is some doubt whether they are real. Beta Cassiopeiæ (magnitude 2·42) is a useful comparison star. The orange hue of *Shedir* is well brought out with binoculars.

MESSIER 31 ANDROMEDÆ. R.A. $0^h\ 40^m{\cdot}7$, Dec. $+41°\ 05'$

The Great Spiral, faintly visible to the naked eye not far from the 4th-magnitude star Nu Andromedæ. It is one of the closest of the external galaxies, and lies at a distance of about 2 million light-years. It must be admitted that in any small or moderate telescope it is a disappointing object, and photographs taken with large instruments are needed to show the spiral form adequately.

H.VIII. 78 CASSIOPEIÆ. R.A. $0^h\ 41^m{\cdot}3$, Dec. $+61°\ 36'$

A fine star-cluster, between Gamma and Kappa Cassiopeiæ. A small telescope will show it well.

GAMMA CASSIOPEIÆ. R.A. $0^h\ 54^m{\cdot}5$, Dec. $+60°\ 31'$

A most extraordinary star, with a spectrum which is classed as B0 (peculiar). It is regarded as a pseudo-nova, since it sometimes undergoes outbursts – for instance in 1936, when it rose to magnitude 1·6. Its normal magnitude is between 2·3 and 2·8. Useful comparison stars are Beta Cassiopeiæ (2·42) and Delta (2·80).

MESSIER 33 TRIANGULI. R.A. $1^h\ 31^m{\cdot}8$, Dec. $+30°\ 28'$

One of the closest of the external galaxies, and a member of the Local Group. Photographs reveal that it is a spiral. In moderate telescopes it is a faint and very difficult object.

GAMMA ARIETIS. R.A. $1^h\ 51^m{\cdot}5$, Dec. $+19°\ 07'$

An excellent double. Magnitudes 4·2, 4·4; position angle 000°; distance $8''{\cdot}4$. Any small telescope will show both components well. It is easy to locate, as it lies close to Beta Arietis.

ALPHA URSÆ MINORIS (*Polaris*). R.A. $1^h\ 58^m{\cdot}6$, Dec. $+89°\ 06'$

The Pole Star. It is of magnitude 2·0, but is actually a cepheid variable of small range. The spectrum is F8. It has a ninth-magnitude companion (p.a. 217°, distance $18''{\cdot}3$) visible with a 3-inch telescope; it is said to be visible even with a 2-inch.

GAMMA ANDROMEDÆ. R.A. $2^h\ 01^m{\cdot}7$, Dec. $+42°\ 09'$

A superb double. The primary is a K-type star of magnitude

2·3; the companion is of magnitude 5, and is bluish (p.a. 061°; distance 9″·7.) The companion is itself a close binary; distance 0″·5, period 55 years. The main pair forms a superb object in a moderate telescope.

H.VI 33–4 PERSEI. R.A. (*for* H.VI. 33) $2^h\ 18^m{\cdot}3$, Dec. +56° 59′

Twin clusters in the 'Sword-Handle' of Perseus; just visible to the naked eye. Each is about 45′ in diameter. Small telescopes will show them adequately; they form one of the most magnificent spectacles in the whole sky. Between the two clusters lies a reddish star.

OMICRON CETI (*Mira*). R.A. $2^h\ 17^m{\cdot}5$, Dec. −3° 08′

The famous variable star. It has an average period of 331 days, and its magnitude range is from 1·6 to 9·6. However, neither the period nor the magnitude range may be regarded as at all constant; at some maxima the magnitude never exceeds 5. The spectrum is of type Me, and the reddish colour makes *Mira* easy to identify.

IOTA CASSIOPEIÆ. R.A. $2^h\ 26^m{\cdot}1$, Dec. +67° 15′

A triple star. Magnitudes 4·2, 7·0, 8·0, p.a's. 251°, 113°; distances 2″·4, 7″.4. Excellently seen with a moderate telescope.

RHO PERSEI. R.A. $3^h\ 02^m{\cdot}9$, Dec. +38° 42′

An M-type irregular variable, not far from *Algol*. The magnitude range is from 3·4 to 4·1; Kappa Persei (4·0) makes a good comparison star. The reddish hue is well brought out in binoculars.

BETA PERSEI (*Algol*). R.A. $3^h\ 05^m{\cdot}8$, Dec. +40° 49′

The 'Demon Star', the prototype eclipsing binary. Its period is 2·87 days. For most of this time it is of magnitude 2·3; it then drops to 3·5 in five hours, and after minimum takes another five hours to climb back to maximum. *Algol* may be studied with the naked eye, and its apparent fluctuations are interesting to follow.

ETA TAURI (*Alcyone*). R.A. $3^h\ 45^m{\cdot}3$, Dec. +24° 00′

The brightest star in the Pleiades (Seven Sisters), the most

conspicuous open cluster in the sky. Keen-sighted persons will be able to see at least eight Pleiads with the naked eye. The best views of the cluster are obtained with binoculars or very low powers on a telescope. The names of the other leading stars in the Pleiades are *Electra*, *Atlas*, *Merope*, *Maia*, *Taygete*, *Celæno*, *Pleione* and *Asterope*.

ALPHA TAURI (*Aldebaran*). R.A. $4^h\ 33^m{\cdot}9$, Dec. $+16°\ 26'$

A K-type reddish star of magnitude 0·85. It is 57 light-years distant, and is ninety times as luminous as the Sun. Extending from it in a rough V are the stars of the very loose cluster known as the Hyades; one of these (Theta Tauri) is a naked-eye double. *Aldebaran* has a faint companion (magnitude 11; p.a. 034°, distance 121″). Actually, *Aldebaran* is not a true member of the Hyades group, and lies between the cluster and ourselves.

EPSILON AURIGÆ. R.A. $4^h\ 59^m{\cdot}4$, Dec. $+43°\ 46'$

The leading member of the 'Hædi' or Kids, a triangle of three faint stars close to *Capella*. Epsilon is an eclipsing binary; the magnitude range is from 3·3 to 4·1, and the period is over 27 years. One component is a very luminous F-type supergiant. The fainter star is invisible, and appears to be the largest individual star known, with a diameter of over 1,800 million miles.

ZETA AURIGÆ. R.A. $5^h\ 00^m{\cdot}0$, Dec. $+41°\ 01'$

The faintest member of the 'Hædi'. It too is an eclipsing binary, though it is not so vast a system as Epsilon. The spectral types of the components are K0 and B1. The mean magnitude is 4·0; the fluctuations are not easy to detect without instrumental aid.

KAPPA LEPORIS. R.A. $5^h\ 11^m{\cdot}6$, Dec. $-12°\ 59'$

A double star; magnitudes 5·0, 7·5; p.a. 000°; distance 2″·6. The primary is yellowish; the companion bluish.

BETA ORIONIS (*Rigel*). R.A. $5^h\ 12^m{\cdot}8$, Dec. $-8°\ 15'$

The leading star of Orion; magnitude 0·15. The distance is thought to be about 540 light-years. *Rigel* is exceptionally lumin-

ous, and is the equal of at least 18,000 Suns. It has a B-type spectrum, and is almost pure white. There is a seventh-magnitude companion (p.a. 202°, distance 9″·4) easily seen in a 3-inch refractor.

ALPHA AURIGÆ (*Capella*). R.A. $5^h\ 14^m{\cdot}0$, Dec. +45° 58′

Magnitude 0·09; spectrum G0. *Capella* is of a yellowish hue, and is a superb object in binoculars. It is an extremely close binary. The distance is 47 light-years, and the luminosity 150 times that of the Sun. Apart from *Arcturus* and *Vega*, it is the brightest star in the northern hemisphere of the sky.

DELTA ORIONIS (*Mintaka*). R.A. $5^h\ 30^m{\cdot}2$, Dec. −0° 19′

The upper star of Orion's belt; it lies almost on the celestial equator. The primary is an eclipsing binary of small range; average magnitude 2·4. There is a seventh-magnitude companion (p.a. 000°, distance 52″·8) which is a very easy telescopic object.

MESSIER 1 TAURI. R.A. $5^h\ 32^m{\cdot}3$, Dec. + 22° 00′

The 'Crab' Nebula; a fascinating object not far from the third-magnitude star Zeta Tauri. It is the wreck of a supernova which was observed by Chinese astronomers in the year 1054. In a small telescope it appears as a faint, diffuse object; large instruments reveal complex detail. The gas-cloud is still expanding from the old explosion-centre.

MESSIER 42 ORIONIS. R.A. $5^h\ 33^m{\cdot}4$, Dec. −5° 24′

In the Sword of Orion; the most prominent gaseous nebula in the sky. It is visible with the naked eye. Excellent views of it are obtained with low powers on small or moderate telescopes. It contains the famous multiple star Theta Orionis, the 'Trapezium' (R.A. $5^h\ 33^m$, Dec. −5° 27′) whose four components are visible in a 3-inch refractor. This superb nebula is always worth looking at.

IOTA ORIONIS. R.A. $5^h\ 33^m{\cdot}7$, Dec. −5° 56′

A double star. Magnitudes 3·2, 7·3; p.a. 141°; distance 11″·4. This is the lowest star of Orion's Sword.

SIGMA ORIONIS. R.A. $5^h\ 36^m{\cdot}9$, Dec. $-2°\ 37'$

Another fine multiple in Orion's Sword. Four stars (magnitudes 4, 10, 7·5, 7) are fairly easy to see with a moderate telescope; larger instruments reveal several more.

ZETA ORIONIS. R.A. $5^h\ 38^m{\cdot}9$, Dec. $-1°\ 58'$

The lowest star of Orion's Belt. The 2·0-magnitude, B-type primary has a 5·0-magnitude companion; p.a. 157°, distance 2″·8. This is a well-known test for a 2-inch refractor.

ALPHA ORIONIS (*Betelgeuse*). R.A. $5^h\ 53^m{\cdot}2$, Dec. $+7°\ 24'$

A particularly interesting star. It is thought to be about 10,000 times as luminous as the Sun, and 650 light-years away. The diameter is about 250 million miles, but this changes somewhat, as the star is an irregular variable. There is a rough period of about five years. The magnitude range is from 0·1 to 1·3. On very rare occasions *Betelgeuse* has been known to outshine *Rigel*. Its orange-red hue makes it a superb sight in binoculars or a low power.

MESSIER 35 GEMINORUM. R.A. $6^h\ 06^m{\cdot}5$, Dec. $+24°\ 21'$

A splendid open cluster near Mu and Eta Geminorum. This is one of the most spectacular cluster-type objects visible with small telescopes.

ETA GEMINORUM. R.A. $6^h\ 12^m{\cdot}7$, Dec. $+22°\ 31'$

A long-period variable; period 231 days, range 3·3 to 4·2. The spectrum is of type M, and the colour orange-red. The neighbouring star Mu, magnitude 3·2 and also of type M, makes a good comparison. The variations of Eta are slow, but may be followed with the naked eye.

BETA MONOCEROTIS. R.A. $6^h\ 27^m{\cdot}1$, Dec. $-7°\ 00'$

A triple star. Magnitudes 5·0, 5·5, 6·0; p.a. 132°, 105°, distances 7″·4, 2″·8. A fine sight in a moderate telescope.

H.VII. 2 MONOCEROTIS. R.A. $6^h\ 30^m{\cdot}7$, Dec. $+4°\ 53'$

A beautiful open cluster just visible to the naked eye.

ALPHA CANIS MAJORIS (*Sirius*). R.A. $6^h\ 43^m{\cdot}6$, Dec. $-16°\ 40'$

The brightest star in the sky. It is of magnitude $-1{\cdot}43$, and has an A0-type spectrum; it is 26 times as luminous as the Sun, and is one of the closest of all stars, since its distance is only 8·6 light-years. It is a wonderful sight in binoculars. The famous companion, Sirius B, is a white dwarf, but unfortunately invisible except in large telescopes.

MESSIER 41 CANIS MAJORIS. R.A. $6^h\ 45^m{\cdot}5$, Dec. $-20°\ 42'$

An open cluster, just visible to the naked eye and excellently seen with low powers.

ZETA GEMINORUM. R.A. $7^h\ 02^m{\cdot}0$, Dec. $+20°\ 38'$

A Cepheid variable. Its magnitude range is from 3·7 to 4·3, and its period is 10·2 days. Nu Geminorum (magnitude 4·1) is a useful comparison star. Zeta has a G-type spectrum, and is rather yellowish.

ALPHA GEMINORUM (*Castor*). R.A. $7^h\ 32^m{\cdot}3$, Dec. $+31°\ 58'$

The senior though fainter of the famous 'Twins'. It was ranked of the first magnitude by the old astronomers, but is now appreciably below; its magnitude is 1·6. It is a fine binary, with a period of 350 years; p.a. 204°, distance 4″. The individual magnitudes of the two components are 2·0 and 2·8. Each is a spectroscopic binary, and the faint eclipsing binary YY Geminorum (=Castor C) is also a member of the system.

BETA GEMINORUM (*Pollux*). R.A. $7^h\ 43^m{\cdot}1$, Dec. $+28°\ 07'$

The orange hue of *Pollux* (spectrum K0) contrasts with the pure white of *Castor*. The magnitude is 1·2, the distance 32 light-years, and the luminosity 28 times that of the Sun.

MESSIER 44 CANCRI. R.A. $8^h\ 38^m$, Dec. $+20°\ 07'$

Præsepe, or the 'Beehive', is a fine open cluster. It is easily

visible to the naked eye on a moonless night, close to the two faint stars Delta and Gamma Cancri. It is well seen with low powers, and is not difficult to resolve into separate stars.

ALPHA HYDRÆ (*Alphard*). R.A. $9^h\ 25^m{\cdot}8$, Dec. $-8°\ 30'$

Alphard, the 'Solitary One', is easy to locate; it lies more or less in line with *Castor* and *Pollux*, and is very isolated. Moreover it is of type K, and decidedly red. *Alphard* is a spectacular object when viewed with binoculars.

GAMMA LEONIS. R.A. $10^h\ 18^m{\cdot}0$, Dec. $+20°\ 01'$

A binary with a period of 407 years. The magnitudes are 2·4 and 3·8; the p.a. 119°, and the distance 4″. The star is easy to identify, as it lies in the famous Sickle of Leo, not far from *Regulus*. It is a fine sight in a moderate telescope.

U HYDRÆ. R.A. $10^h\ 35^m{\cdot}8$, Dec. $-13°\ 12'$

An N-type irregular variable, with a range from magnitude 4·5 to 6. It is the brightest of the stars of spectrum N, and its deep-red colour makes it of great interest.

MESSIER 97 URSÆ MAJORIS. R.A. $11^h\ 12^m{\cdot}6$, Dec. $+55°\ 13'$

The 'Owl' nebula. It is 3′ in diameter, and is one of the interesting objects known as planetary nebulæ. It is not, however, very conspicuous, and will hardly be seen in a small telescope.

GAMMA VIRGINIS. R.A. $12^h\ 39^m{\cdot}8$, Dec. $-1°\ 15'$

One of the most spectacular binaries in the sky. Each component is of type F0, and the magnitudes are almost equal at 3·6. The period is 180 years, and the separation is becoming steadily less, but it is still well over 5″, so that the components are excellently seen in a small telescope.

ALPHA CANUM VENATICORUM (*Cor Caroli*). R.A. $12^h\ 54^m{\cdot}3$, Dec. $+38°\ 31'$

An easy double. Magnitudes 3·1, 5·6; p.a. 228°; distance 19″·7.

ZETA URSÆ MAJORIS (*Mizar*). R.A. 13h 22m·5, Dec. +55° 07′

The second star in the Plough-handle. It forms a naked-eye pair with *Alcor* (magnitude 5). *Mizar* is itself a binary; magnitudes 2·2, 4·2; p.a. 150°, distance 14″·5. In any small telescope the components are easily separated. With low powers *Alcor* also is in the field, and between it and *Mizar* is yet another star. This is one of the best binary objects for small apertures, particularly as *Mizar* is so easy to locate.

MESSIER 3 CANUM VENATICORUM. R.A. 13h 40m·6, Dec. +28° 34′

A bright globular cluster on the borders of Canes Venatici and Boötes. With a moderate telescope, the cluster is fully resolvable into stars.

ALPHA BOÖTIS (*Arcturus*). R.A. 14h 14m·0, Dec. +19° 22′

Apart from *Sirius*, *Arcturus* is the brightest star visible from the latitude of Britain. Its magnitude is −0·06, its distance 41 light-years, and its luminosity 100 times that of the Sun. The spectrum is of type K, and *Arcturus*' glorious orange hue makes it a fine sight with binoculars or a low power.

EPSILON BOÖTIS. R.A. 14h 43m·4, Dec. +27° 14′

A third-magnitude star with a sixth-magnitude companion at distance 2″·8, p.a. 335°. The primary is yellowish, the companion bluish.

R CORONÆ BOREALIS. R.A. 15h 47m·1, Dec. +28° 15′

A curious irregular variable. For long periods the magnitude remains at 6, and then drops suddenly, sometimes to below 12. After a period of minimum brilliancy, which may be protracted, the star rises once more to magnitude 6. The causes of this behaviour are unknown, and amateur observers can do valuable work by studying R Coronæ and other stars of its type.

T CORONÆ BOREALIS. R.A. 15h 58m·0, Dec. +26° 01′

The 'Blaze Star'. Normally it is of below magnitude 8, but it has

suffered two major outbursts – one in 1866 (magnitude 2) and the other in 1946 (magnitude 4). Minor fluctuations are always going on, and the star merits close attention from amateur observers.

BETA SCORPIONIS. R.A. $16^h\ 03^m{\cdot}3$, Dec. $-19°\ 42'$

Magnitudes 3·0, 5·2; p.a. 023°; distance 14″. This is a wide, easy double.

MESSIER 80 SCORPIONIS. R.A. $16^h\ 14^m{\cdot}9$, Dec. $-22°\ 53'$

A bright globular cluster between *Antares* and Beta Scorpionis. Well seen in a moderate telescope.

MESSIER 4 SCORPIONIS. R.A. $16^h\ 21^m{\cdot}5$, Dec. $-26°\ 26'$

An open cluster, close to *Antares*. The diameter is about 14′, and the whole cluster is easily resolvable.

ETA DRACONIS. R.A. $16^h\ 23^m{\cdot}5$, Dec. $+61°\ 36'$

A G5-type star of magnitude 2·9, with an eighth-magnitude companion at p.a. 142°, distance 6″·1. It is a test for a 3-inch refractor.

ALPHA SCORPIONIS (*Antares*). R.A. $16^h\ 27^m{\cdot}2$, Dec. $-26°\ 21'$

The 'Rival of Mars'. *Antares* is an M-type supergiant, 3,400 times as luminous as the Sun, and 360 light-years away. It is strongly red in hue, and has a seventh-magnitude greenish companion at p.a. 275°, distance 3″. For some time *Antares* was believed to be the largest star known; though it is in fact surpassed by others, it is still of exceptional size. It is unfortunate that it never rises very high over the British horizon.

ZETA HERCULIS. R.A. $16^h\ 39^m{\cdot}9$, Dec. $+31°\ 40'$

A splendid binary with a period of 34 years. The distance reached 1″·6 in 1954, and is now decreasing. The primary is a star of spectral type G0, magnitude 3; the companion is of magnitude 6·5.

MESSIER 13 HERCULIS. R.A. $16^h\ 40^m$, Dec. $+36°\ 31'$

The brightest of the globular clusters visible from the latitude

of Britain. It may be seen with the naked eye on a clear night, and lies between Zeta and Eta Herculis, considerably closer to Eta. With a moderate telescope, it is fully resolvable, and is a magnificent sight, but in very small instruments it is somewhat disappointing.

ALPHA HERCULIS. R.A. $17^h\ 13^m{\cdot}0$, Dec. $+14°\ 26'$

One of the most interesting stars in the sky. The primary is an M-type supergiant, variable between magnitudes 3 and 3·7 in an irregular manner; it has the distinction of being one of the largest stars known. The companion (magnitude 6, p.a. 112°, distance 4″·5) is distinctly green. In a moderate telescope the colours make a superb contrast. The fluctuations of the primary may be followed with the naked eye; Kappa Ophiuchi (magnitude 3·4) makes a useful comparison star.

MESSIER 92 HERCULIS. R.A. $17^h\ 16^m{\cdot}1$, Dec. $+43°\ 11'$

A globular cluster between Eta and Iota Herculis. It resembles M13, but is much less conspicuous.

MESSIER 7 SCORPIONIS. R.A. $17^h\ 51^m{\cdot}6$, Dec. $-34°\ 48'$

A magnificent open cluster near the Scorpion's 'sting'. Unfortunately it is never well seen in Britain, as it is always low in the sky.

MESSIER 23 SAGITTARII. R.A. $17^h\ 54^m{\cdot}8$, Dec. $-19°\ 01'$

An open cluster almost 50′ in diameter, well seen with a low power.

H.IV. 37 DRACONIS. R.A. $17^h\ 58^m{\cdot}6$, Dec. $+66°\ 38'$

One of the brightest of the planetary nebulæ. It is well seen with a moderate telescope.

MESSIER 8 SAGITTARII. R.A. $18^h\ 01^m{\cdot}4$, Dec. $-24°\ 23'$

The 'Lagoon' nebula. This is a gaseous nebula, and is contained in our own Galaxy. It is faintly visible with the naked eye, and moderate telescopes show a large amount of detail; there are

bright patches and dark rifts. This whole area is rich in nebular objects, and is well worth sweeping.

N.G.C. 6572 OPHIUCHI. R.A. $18^h\ 10^m{\cdot}9$, Dec $+6°\ 50'$

A small, bright planetary nebula, lying between Beta Ophiuchi and Zeta Aquilæ. It is an easy object in a small telescope.

MESSIER 17 SAGITTARII. R.A. $18^h\ 18^m{\cdot}8$, Dec. $-16°\ 12'$

The 'Omega' nebula. The nearest naked-eye star is Gamma Scuti. Like the Lagoon, this is a gaseous nebula contained in our own Galaxy, and is large and bright, with abundant detail.

ALPHÆ LYRÆ (*Vega*). R.A. $18^h\ 35^m{\cdot}7$, Dec. $+38°\ 45'$

Vega is the brightest star in the northern hemisphere of the sky, apart from *Arcturus*. Its magnitude is 0·0, its spectral type A0, its distance 26 light-years and its luminosity 50 times that of the Sun. It is notable because of the distinctly bluish cast which makes it a superb object in low powers. It has a companion of magnitude 10·5, at p.a. 170°, distance 56″. This is an optical pair, and not a binary; the companion is faint and moreover overpowered by the brilliance of the primary, so that it is not a particularly easy object. *Vega* is very high up during summer evenings, and cannot be mistaken.

EPSILON LYRÆ. R.A. $18^h\ 43^m{\cdot}2$, Dec. $+39°\ 34'$

A fascinating quadruple star. Epsilon^1 and Epsilon^2 form a naked-eye pair (distance 208′), and are easy to find, since they lie near *Vega*. Each is again double; Epsilon^1 (magnitudes 4·6, 6·3; p.a. 005°; distance 3′) and Epsilon^2 (4·9, 5·2; 111°; 2″·3) and there are various other stars in the same low-power field. This is a particularly good object for viewing with a small or moderate telescope.

ZETA LYRÆ. R.A. $18^h\ 43^m{\cdot}5$, Dec. $+37°\ 34'$

A wide, easy double. Magnitudes 4·2, 5·5; p.a. 150°; distance 44″.

BETA LYRÆ. R.A. $18^h\ 48^m{\cdot}8$, Dec. $+33°\ 19'$

The prototype 'ellipsoidal' variable. It is not in fact a true

variable, but is an eclipsing binary of special type. The maximum is magnitude 3·4; the minima are alternately of magnitude 3·8 and 4·1; the period is 12·9 days. Gamma Lyræ (magnitude 3·3) is a useful comparison star. The system of Beta Lyræ is of particular interest from an astrophysical point of view. The spectra are B8 and B2, but each is peculiar, and the components are too close to be separated visually.

MESSIER 11 SCUTI. R.A. $18^h\ 49^m{\cdot}0$, Dec. $-6°\ 19'$

The 'Wild Duck'. A superb open cluster, not far from Lambda Aquilæ. It is faintly visible to the naked eye. A moderate telescope shows it as a fan-shaped cluster, with a bright star at its apex.

MESSIER 57 LYRÆ. R.A. $18^h\ 52^m{\cdot}6$, Dec. $+32°\ 59'$

The 'Ring' nebula. This is the most famous of the nebulæ, and is extremely easy to find, as it lies between Beta and Gamma Lyræ. In a small telescope it does indeed look like a ring; the dark centre is easy to see, but the central star is a difficult object.

THETA SERPENTIS. R.A. $18^h\ 54^m{\cdot}4$, Dec. $+4°\ 09'$

One of the best double stars for a small telescope. The components are almost equal at magnitude 4·1; the p.a. is 103°, and the distance 22″·3. The star is easy to find, as it lies almost in a line with Theta, Eta and Delta Aquilæ. Each component is white.

BETA CYGNI. R.A. $19^h\ 29^m{\cdot}3$, Dec. $+27°\ 53'$

Beta Cygni (*Albireo*) is probably the loveliest double star in the sky. It is an easy object; the magnitudes are 3·0 and 5·3, the p.a. 055°, and the separation 35″, so that any small telescope will show it. The contrasting colours make it striking; the primary is yellow, while the companion is strongly bluish-green. *Albireo* appears the faintest of the five stars which make up the cross of Cygnus, but it is in fact a very luminous star lying at a great distance from us.

CHI CYGNI. R.A. $19^h\ 49^m{\cdot}2$, Dec. $+32°\ 49'$

An M-type long-period variable. The range is from magnitude

4 to 14, and the period 409 days; it is the *Mira* type. When near maximum it is easily visible to the naked eye, and may be compared with its near neighbour Eta Cygni (magnitude 4). Near minimum, a powerful telescope is needed to show it.

ETA AQUILÆ. R.A. $19^h\ 50^m{\cdot}6$, Dec. $+0°\ 55'$

Spectrum G0 (peculiar). Eta is a typical Cepheid variable, with a range from magnitude 3·7 to 4·5, and a period of 7·18 days. It lies between Delta (magnitude 3·4) and Theta (also 3·4), which are useful as comparison stars.

MESSIER 27 VULPECULÆ. R.A. $19^h\ 58^m{\cdot}1$, Dec. $+22°\ 37'$

The curious galactic 'Dumb-bell' nebula, not far from Gamma Sagittæ. It is a faint object in a small telescope, but is well worth looking for.

ALPHA CAPRICORNI. R.A. $20^h\ 15^m{\cdot}8$, Dec. $-12°\ 39'$

A naked-eye double; Alpha^1 and Alpha^2, of magnitudes 3·7 and 4·3 respectively, are separated by 378″. Alpha^1 has a ninth-magnitude companion at 45″. Alpha^2 is itself a difficult double; the companion is of magnitude 11, position angle 158°, distance 7″. Since the faint companion is a close binary, the whole system is decidedly complex.

ALPHA CYGNI (*Deneb*). R.A. $20^h\ 40^m{\cdot}2$, Dec. $+45°\ 09'$

The brightest star of Cygnus. It is of magnitude 1·3, and has a peculiar A2-type spectrum. It is an exceptionally luminous star, at least 10,000 times as brilliant as the Sun, and is of great interest to astrophysicists. Its yellowish colour is well shown by use of a low power.

GAMMA DELPHINI. R.A. $20^h\ 45^m{\cdot}0$, Dec. $+16°\ 00'$

A wide, easy double. Magnitudes 4, 5; p.a. 270°, distance 10″·4. The primary is yellowish, the companion greenish.

H.IV. 1 AQUARII. R.A. $21^h\ 02^m{\cdot}1$, Dec. $-11°\ 31'$

A bright planetary nebula, known as the Saturn nebula for

reasons which will be obvious when the object is studied with a large aperture. In smaller telescopes the Saturn-like appearance is not seen, but nevertheless the nebula is a most interesting object. It lies near the fourth-magnitude star Nu Aquarii.

61 CYGNI. R.A. $21^h\ 05^m{\cdot}3$, Dec. $+38°\ 34'$

An easy binary; magnitudes 5·3, 5·9; p.a. 134°; distance 25″. 61 Cygni is famous as being the first star to have its distance measured – by Bessel, in 1838. The system is about 11 light-years away. Both components are dwarfs, and the fainter (B) is suspected to have a large planet associated with it.

MESSIER 15 PEGASI. R.A. $21^h\ 28^m{\cdot}3$, Dec. $+12°\ 01'$

A splendid globular cluster not far from Epsilon Pegasi (magnitude 2·5). A small telescope will show it well.

BETA CEPHEI. R.A. $21^h\ 28^m{\cdot}2$, Dec. $+70°\ 24'$

A third-magnitude star with an eighth-magnitude companion at p.a. 250°, distance 13″·7. As it is circumpolar, it makes a useful test (for small apertures) which is available on any clear night.

MESSIER 39 CYGNI. R.A. $21^h\ 31^m{\cdot}0$, Dec. $+48°\ 17'$

A large open cluster, between *Deneb* and Alpha Lacertæ, well seen with low powers.

MU CEPHEI. R.A. $21^h\ 42^m{\cdot}4$, Dec. $+58°\ 36'$

The 'Garnet Star' of Sir William Herschel. It is a *Betelgeuse* type irregular variable, but since its fluctuations lie between magnitudes 4 and 6 it is never brilliant. However, any optical aid will bring out its lovely red colour; it has been compared with a glowing coal.

DELTA CEPHEI. R.A. $22^h\ 27^m{\cdot}8$, Dec. $+58°\ 14'$

The prototype Cepheid. It changes between magnitudes 3·7 and 4·3 in a period of 5·37 days. Its neighbour Zeta (magnitude 3·6) makes a useful comparison star.

ALPHA PISCIS AUSTRINI (*Fomalhaut*). R.A. $22^h\ 55^m.7$, Dec. $-29°\ 49'$

This is the southernmost of the first-magnitude stars visible from Britain. It can be quite conspicuous from southern England, but from northern Scotland it is always extremely low down. It is of spectrum A3, and is 13 times as luminous as the Sun. As it lies at a distance of only 24 light-years, it is the nearest of the first-magnitude stars apart from *Sirius*, *Procyon* and *Alpha Centauri*.

BETA PEGASI. R.A. $23^h\ 02^m.0$, Dec. $+27°\ 53'$

An M-type variable of the *Betelgeuse* class. Its range is between magnitudes 2·3 and 2·8, and there is a very rough period of about five weeks. It is one of the stars making up the Square of Pegasus, and good comparisons are Alpha Pegasi (2·6) and Gamma (2·9). Beta is strongly orange in hue, and its alterations in brightness may be followed with the naked eye. Incidentally, it is instructive to select a clear night and then count the number of naked-eye stars contained in the Square of Pegasus. There are not very many of them!

Biographical Notes on Contributors

H. G. MILES, lecturer at the Lanchester College of Technology, Coventry, is the Director of the Artificial Satellite Section of the British Astronomical Association, and has collaborated extensively with scientists in Britain and abroad in connexion with tracking the various Earth satellites.

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HENRY BRINTON is the author of numerous political works, as well as novels. He is also known as a children's science writer, and is a frequent broadcaster on sound and television. His private observatory at Selsey, in Sussex, is equipped with a 12½-inch optical reflector as well as a home-made radio telescope. He was elected to the Council of the British Astronomical Association in 1962.

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